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Federation Affairs

Two British Associations Affiliate with the Federation of Sewage Works Associations

Two notable British associations have voted to affiliate with the Federation of Sewage Works Associations.

The Institution of Sanitary Engineers, through Secretary A. D. Hamlyn, 122 Victoria Street, Westminster, S. W. 1, applied for affiliation and was elected by letter ballot of August 4, 1932. The Council of the Institution voted to form an inner group of those members interested in the field covered by the SEWAGE WORKS JOURNAL. Mr. Buffum received a list of twenty members, accompanied by a $2.00 subscription for each of these members, and their subscriptions began as of August 8, 1932.

The Association of Managers of Sewage Disposal Works had been invited to affiliate with the Federation, following action of the 1932 Annual Meeting of the Board of Control of the Federation (THIS JOURNAL, March, 1932, p. 240). Through the efforts of H. W. Streeter, Chairman of the Membership Committee, this affiliation was effected as of Sept. 2, 1932, and a list of subscribers to the JOURNAL has been sent to Mr. Buffum. The Secretary of the British Association is Mr. J. B. Croll, 1 Main Drainage Works, West Hall Road, Kew Gardens, Surrey.

The Institution publishes monthly abstracts of engineering articles, and the Association of Sewage Works Managers issues an annual volume containing proceedings of and papers presented at the various district meetings and the annual meeting in London. These proceedings include the most important English papers on sewage treatment, and the discussions are invaluable.

Affiliation with these two societies should be of mutual benefit, and will widen the scope of circulation of our JOURNAL. President Emerson, Mr. Streeter and Mr. Buffum are to be congratulated for bringing about this affiliation with the two leading British associations identified with sewage disposal.

Sewage Research

Recommended Uniform Procedure for Biochemical Oxygen Demand Determinations

Progress Report—Joint B. O. D. Committee of the Great Lakes and Ohio River Boards of Public Health Engineers

April 11–12, 1932

Reviewed and Approved by the Committee on Methods of Sewage Analysis of the Federation of Sewage Works Associations

Foreword

The Joint Committee of the Great Lakes and Ohio River Boards of Public Health Engineers was appointed during December, 1928, for the purpose of coördinating methods for biochemical oxygen demand determinations (B. O. D.) to facilitate obtaining directly comparable data in interstate water pollution surveys and in coöperative studies of sewage and industrial waste treatment. The Joint B. O. D. Committee carefully reviewed analytical procedures used by various laboratories in states included within the Ohio River and Great Lakes drainage basins, and decided to establish a "tentatively standard" dilution water as a first step toward securing uniformity in methods employed. At a meeting on June 28, 1930, it was agreed by the Committee to use distilled water to which has been added 0.3 gram per liter of sodium bicarbonate as such a "tentatively standard" dilution water, and then carry out studies of a comparative nature with natural and other synthetic dilution waters, using certain sewages and trade wastes. At a meeting held December 5–6, 1930, information obtained was reviewed and a progress report was prepared, setting forth in considerable detail the technique advocated for use in B. O. D. determinations. This progress report under the title of "Tentatively Standard Procedure for B. O. D. Determinations" was mimeographed and made available for use by the Great Lakes and Ohio River Boards of Public Health Engineers. Further research work was outlined to ascertain more definitely the range of applicability of methods proposed. It was particularly anticipated that special modifications would be necessary with certain trade wastes, such as the special procedure set up for use with sulphite and sulphate pulp mill effluents. The studies conducted to date have been used as a background for the following progress report of the Joint B. O. D. Committee.

The Committee on Methods of Sewage Analysis of the Federation of Sewage Works Associations was appointed by President C. A. Emerson, Jr., at the Annual Meeting in January, 1930. The Committee has reported on the Determination of Dissolved Oxygen by the Winkler Method (THIS JOURNAL, *May, 1932, pages 413–427*). *Inasmuch as that report is almost identical with the report of the Great Lakes-Ohio River Boards on the determination of dissolved oxygen, the latter has not been reprinted.*

The following report on analytical procedure for the determination of the biochemical oxygen demand of polluted waters, sewage and trade

wastes is recommended by the Joint B. O. D. Committee of the Great Lakes and Ohio River Boards of Public Health Engineers and the Committee on Methods of Sewage Analysis of the Federation of Sewage Works Associations for adoption as a uniform method in interstate pollution control activities, and for use in operation of sewage treatment works.

Apparatus

1. **Sample and Incubation Bottles.**—The use of 300-ml.[1] narrow-neck bottles with accurately fitting glass stoppers is recommended. The

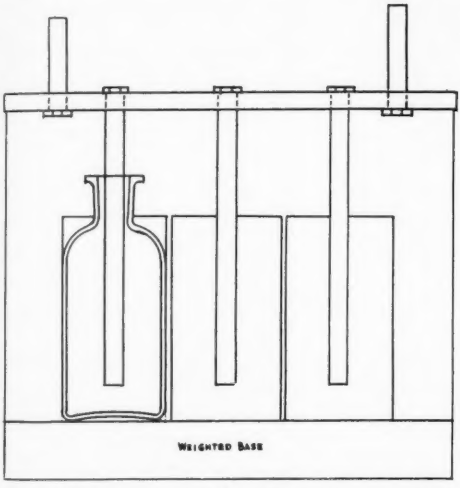

FIG. 1.—Fundamental Requirements: 1. Total Volume of Container Must Be at Least Four Times the Total Volume of Sample Bottles. 2. Incoming Water Must Be Delivered Through Tubes to a Point near Bottom of Sample Bottles.

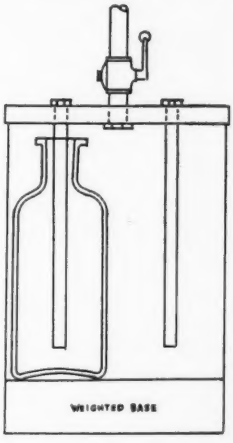

FIG. 2.—Essentially as Shown in Fig. 1 Except for Air Release Valve Allowing Sample to Be Taken at Any Specified Depth.

stoppers are to be numbered to correspond with numbers on the bottles. Cleaning of bottles is essential, the use of concentrated sulphuric acid (or cleaning mixture) followed by thorough rinsing being recommended. In field work, where weight is a factor, the use of smaller bottles (125 ml. or less) is allowable, the volumes of reagents being proportionately reduced.

2. **Sampling Equipment.**—See Figures 1 and 2 for recommended types of sampling devices.

3. **Seals.**—Seals are to be used for all periods of incubation in B. O. D. determinations.

[1] *The abbreviation "ml." for milliliter or milliliters is used throughout instead of "cc."*

4. Incubator.—Capable of regulation at 20° C. ± 1° C. A constant temperature room is desirable.

Sampling

The sampling equipment should be such that the liquid in the sampling bottle is displaced at least three times without entrainment of air bubbles.

In sampling from streams, ponds or tanks of moderate depth, apparatus of the type in Figure 1 may be used. It will be noted that the sample bottles will begin to fill as soon as this type of apparatus is submerged. If it is desired to obtain samples from a considerable depth, a sampler with a valve release, as shown in Figure 2, may be used. Electrical release devices have been used for this purpose. Samplers of the types shown may be designed for the simultaneous collection of several samples to be used for bacteriological, dissolved oxygen and oxygen-demand determinations.

Wide-mouthed vessels are to be used for sampling sewage and trade wastes, and sample collectors should be instructed to dip well below the surface of the liquid. As soon as possible after collection, a suitable amount of the sample (if composite samples are to be made) should be transferred to a proper container. Wastes subject to rapid decomposition should, if possible, be kept on ice or in an icebox until samples are prepared for incubation. Samples should be transported to the laboratory promptly, and examination not be delayed.

In collecting samples for oxygen demand tests, information should be secured regarding the temperature and rate of flow of the waste. In the absence of such information, interpretation of the data may be difficult or impossible.

With sewage and trade wastes, hourly samples proportioned to the volume of flow at the time of sampling should be collected over a full 24-hour period and composited for analysis. The use of direct-reading, flow-measuring devices is recommended.

In the absence of flow-measuring devices, hourly samples of adequate size may be collected throughout the sampling period and composited for analysis. With industrial wastes composite samples covering at least one complete period of plant operation (such as the digestor blow-off period in a sulphite pulp mill) should be collected, samples being proportioned to the volume of flow as nearly as possible.

In rare cases where the character of the waste or sewage varies little from day to day and where its composition throughout the day has been fully established, it may be sufficient to collect a single sample at a particular hour which corresponds to average conditions. *In general, however, no reliance can be placed on catch samples.*

There is need for the further development of automatic devices for the sampling of sewage and industrial wastes. Such devices as are described

by Edwards in "How to Measure White Water Losses," *Paper Industry*, Vol. **7**, No. 2, pp. 215–220, have been of assistance in securing representative samples.

Dilution Water

It is essential that the dilution water should possess the following characteristics at the time of use:

(*a*) Its 10-day oxygen demand should be less than 0.6 p. p. m., or its 5-day demand should be less than 0.2 p. p. m.

(*b*) It should be neither supersaturated nor greatly undersaturated with dissolved oxygen at the standard temperature of 20° C.; that is, it should contain between 8.0 and 9.0 p. p. m. of dissolved oxygen.

(*c*) The temperature of the dilution water should be approximately 20° C. The water may be brought to this temperature by storage at 20° C. until fully saturated with oxygen.

(*d*) The water should be practically free from interfering substances, such as iron salts and nitrites, and from inhibitory substances, such as free chlorine, chloramines and copper salts.

(*e*) The pH value and the mineral salt content of the water should be favorable to biological growth.

Inasmuch as available data and information indicate that results obtained with sewage and industrial wastes, when distilled water alone is used for dilution purposes, are relatively low, and as synthetic waters may be prepared easily, the use of distilled water in the B. O. D. determination is inadvisable.

In investigations of specific stream pollution problems, it may be desirable that the composition of the dilution water, as well as its pH value and its degree of mineralization approximate that of the receiving body of water.

In many localities, such a water may be obtained conveniently by the storage of natural water at 20° C. until its oxygen demand has been suitably reduced. Use of stored natural water in a given situation, however, may not permit ready comparison with results obtained elsewhere.

It is recognized that very frequently it may be impossible to secure a suitable dilution water from natural sources of supply. For purposes of comparison, it is desirable to provide a dilution water of readily reproducible characteristics. Extended comparisons of various synthetic dilution waters have indicated that, within the usual limits of error, a considerable latitude is allowable in the degree of mineralization and in the nature of the mineral salts, provided that the pH value of the dilution waters is somewhat the same.

Distilled water which has been stored at 20° C. until fully saturated

with oxygen and to which has been added 0.3 gram per liter of sodium bicarbonate (corresponding to 300 p. p. m.) is recommended as a dilution water. A fully aerated distilled water should be obtained if the distillate, suitably cooled, is allowed to drip into the receiving vessel. Realizing that this water may not be most satisfactory for meeting all requirements, its use is advocated as a step toward securing more directly comparable B. O. D. results between states signatory to the Great Lakes and Ohio River Drainage Basin Sanitation Agreements.

A number of synthetic waters have been proposed for use in the B. O. D. determination. Only a limited amount of research of a comparative nature has been conducted with these waters. Some of these waters may ultimately be found to be more satisfactory for general application than the easily prepared sodium bicarbonate dilution water. There is a definite need, therefore, for further coördinated research between the states concerned using different sewages and various types of industrial wastes before drawing final conclusions regarding the suitability of a given synthetic water. The posssible advantageous use among various synthetic waters of one buffered at a pH value which corresponds to average conditions, such as can be prepared from potassium acid phosphate (KH_2PO_4), should be given more exhaustive study. Particularly is this true with nitrified or partly nitrified sewage effluents.

Preliminary Treatment of Samples

1. Adjustment of pH Value.—Biological activity may be inhibited if a sample is unduly acid (pH 5.5 or less) or if it is unduly alkaline (pH 9.0 or greater). In such cases the adjustment of the hydrogen-ion concentration to a value within these limits or else to a value corresponding to that of the receiving body of water (as a rule, pH 6.5 to 8.0) appears to be the most logical procedure. It is to be borne in mind that when acid or alkaline samples are highly diluted, the buffer strength of the dilution water may be sufficient to maintain a favorable pH value without adjustment.

The amount of acid or alkali to be added for adjustment of the sample should be determined on a test portion of the sample.

If the sample is unduly acid, a dilute solution of sodium carbonate (10.6 grams of Na_2CO_3 per liter gives a 0.1 *M* solution) is added until the test portion reacts alkaline to brom thymol blue.

If the sample is unduly alkaline, a dilute solution of hydrochloric acid (17.1 ml. of concentrated HCl, sp. gr. 1.19, per liter, gives a 0.2 *M* solution) is added until the test portion reacts acid to cresol red.

Suitable allowance must be made for dilution occasioned by the addition of the alkali or acid.

2. Seeding.—As the test depends on the symbiotic activity of

bacteria and plankton it is necessary to insure at all times the presence of both classes of organisms. This precaution is of particular importance in the examination of industrial wastes, and chlorinated raw sewage or sewage effluents.

The seeding is to be accomplished by adding sewage (1 ml. or less per liter) or river water (10 to 20 ml. per liter) to the dilution water. In the case of chlorinated sewage or sewage effluents, the seeding may not be effective unless all of the chlorine and chloramine compounds have been dissipated.

3. Supersaturation.—Samples collected during the winter months or from localities where algae are actively growing may be supersaturated (over 9.17 p. p. m.) with dissolved oxygen with reference to a temperature of 20° C. To allow for fluctuations in temperature, the following procedures should be applied whenever the dissolved oxygen content exceeds, say, 9.0 p. p. m. The procedures are given in order of preference and in each case the duration of the treatment is to be determined empirically.

(*a*) Suction may be applied to a bottle partly filled with the sample after the temperature of the sample has been raised to approximately 20° C. The release of oxygen is greatly accelerated by agitation.

(*b*) The sample may be mildly preheated in a water-bath. The excess oxygen is then liberated by agitation and the sample is cooled to 20° C. The temperature of the water-bath should not exceed, say, 30° C.

(*c*) Compressed air may be passed through the sample.

The possibility of diluting the sample with deaerated water should also be borne in mind.

The use of devices for entrapping oxygen liberated from supersaturated samples during incubation is not recommended.

4. Undersaturation.—Within reasonable limits, undersaturation is not objectionable. Under certain winter conditions, however, samples may be received which are deficient in dissolved oxygen although they do not possess a high enough oxygen demand to warrant dilution with aerated water. The oxygen content of an undersaturated sample may be raised by agitating it in a partly filled bottle after bringing the temperature of the water to 20° C.

Choice of Concentrations

With relatively unpolluted river water, dilution is seldom necessary. Sewage effluents of excellent quality may likewise frequently be incubated without dilution, at least over the usual 5-day period of incubation.

With normal sewage it is necessary to dilute the samples to such an extent that the depletions of oxygen fall within the limits of, say, 2.0 to 8.0 p. p. m., when the initial oxygen content is 9.0 p. p. m. If the depletions are very small (2.0 p. p. m. or less) the percentage error becomes

great. Conversely, it is desirable that at least 1 p. p. m. of dissolved oxygen or thereabouts be present at the completion of the test. With nitrified effluents, such as sewage after complete treatment, dilutions should be such as to allow at least 2 p. p. m. residual oxygen at the end of the incubation period. For average American sewage, trial concentrations of 2.5 to 5 per cent are suggested.

With industrial wastes of uncertain or unknown characteristics, several concentrations of sample should be prepared, each 50 per cent of the next highest until the desired range has been compassed. Sometimes it is advantageous to make a permanganate oxygen consumed test as an aid in determining the possible range of concentrations. The actual number of concentrations to be incubated will depend on the certainty with which the behavior of the sample is known and it will be governed to some extent by the period of incubation.

Dilution Technique

Starting with a waste which must be diluted prior to incubation, the essential requirement in the preparation of a series of concentrations is that the subsamples be uniform in regard both to distribution of sample and to dissolved oxygen content. Although the technique actually used will depend on individual preferences, the following general considerations should apply:

(*a*) If only one concentration of a waste is required for determining the oxygen demand of a waste over a single period of incubation, it is convenient to prepare a stock solution which may afterward be transferred to the incubation bottles.

Thus, to prepare a 10 per cent concentration, a liter flask is partly filled with diluting water, 100 ml. of sample is added and the liter flask is made up to the mark with dilution water, moving the siphon up and down to secure good mixing. The contents of the flask are then siphoned to three incubation bottles of approximately 300 ml. capacity, the first portion going over being rejected in order to clean the siphon and to clear it of air bubbles. In siphoning the samples to the incubation bottles, the delivery tube should be kept below the surface of the liquid to prevent the mechanical entrainment of air bubbles. The oxygen content of the dilution water is not greatly changed when this technique is followed.

Likewise, the sample may be added to a liter graduate, mixing being secured by a suitable stirring device.

More conveniently, a 10 per cent concentration may be secured by adding 100 ml. of sample to a large bottle, followed by the addition of a measured volume of 900 ml. of dilution water or by making up with dilution water to a pre-determined mark, depending on the accuracy desired. The sample is then mixed by agitation and siphoned into bottles as before,

after air bubbles have disappeared. A large separatory funnel may be used to advantage if this procedure is adopted. This procedure insures complete mixing but it presupposes that the initial oxygen content of the sample is to be determined by actual analysis and not by computation.

(*b*) If a series of concentrations of the same waste is being prepared, it may be convenient to put up one concentration stronger than actually desired and to prepare the others from it. Thus, if the desired concentrations are to contain 1.0, 0.5, 0.25 and 0.125 per cent of sample, a stock solution containing 5 per cent of the sample may first be prepared by diluting 25 ml. of the sample to 500 ml. Proper mixing of the stock solution may be secured by moving the siphon up and down while filling or by blowing back the first 50 or 100 ml. pipetted. The required concentrations may then be obtained by taking portions of 200, 100, 50 and 25 ml. from the stock solution and diluting each amount to one liter as described above. This procedure lessens the sampling error, especially if the concentrations are small.

The dilution technique is greatly simplified when suitable amounts of sample are added directly to bottles of known capacity, the bottles then being filled with dilution water. The amounts added using such technique should not be less than 2.5 ml. This procedure presupposes that the volumes of the dilution bottles have been accurately determined.

Initial Dissolved Oxygen Content

The initial dissolved oxygen content of the dilution water, must, of course, be determined in all cases. If the oxygen content of the waste is also known, the initial oxygen content of the diluted waste may be computed from the amount of waste added. Very frequently, however, it may be difficult or else unnecessary to determine the dissolved oxygen content of the undiluted waste. If the dilution technique is such that the oxygen content of the dilution water is not greatly changed during the manipulations, it may be possible to gain some information regarding the oxygen content of the undiluted waste by a consideration of the value found for the oxygen content of the diluted mixture. The three following cases should be borne in mind:

(*a*) The oxygen content found analytically is the same as that computed on the assumption that the waste was devoid of oxygen, *i. e.*, the waste has no dissolved oxygen and no initial oxygen demand. In this case, if the initial oxygen content of the dilution water is 8.0, the dissolved oxygen content of a 10 per cent concentration is obviously 7.2 parts per million.

(*b*) The diluted sample shows a higher dissolved oxygen content than the computed value, *i. e.*, the waste contains dissolved oxygen. In this case, of course, the observed value should be used.

(*c*) The diluted sample shows a lower dissolved oxygen content than the computed value, *i. e.*, the waste has an initial oxygen demand. In this case the computed value should be used, since it corresponds to the oxygen which was actually present at the start of the test.

If several concentrations are put up at the same time, the initial oxygen content of one is determined and that of the others is computed. If the concentrations are all less than 1 per cent, the value which corresponds to the oxygen content of the dilution water may be assumed.

Appropriate methods for the determination of dissolved oxygen were given in THIS JOURNAL, May, 1932, p. 413.

Immediate Oxygen Demand

General rules cannot be given for estimating the immediate or purely chemical demand of industrial wastes, each waste constituting a separate problem. With certain wastes (for example, mine drainage and pickling liquors) the possibility exists of measuring the immediate demand chemically by a direct estimation of known reducing agents (in this case, ferrous iron). Probably the most satisfactory method of procedure is to follow the disappearance of dissolved oxygen by a gasometric analysis of the air contained in a bottle partly filled with the sample under examination.

Sealing of Samples

For periods of incubation of 5 days at 20° C., the use of seals does not appear essential when a carefully regulated incubator is available, if the incubator can be kept saturated with moisture. It is recommended, however, as a uniform procedure that seals be provided for all periods of incubation.

Under less favorable conditions of temperature and humidity control, it may be desirable to provide for volume changes: (*a*) by "jointing" the sample with a rubber collar, as shown in Figure 3, (*b*) by the use of a bottle provided with a large cup (see Figure 3) or, better, (*c*) by immersing the samples in water.

Period of Incubation

Relations existing between the oxygen demand values corresponding to various periods of incubation are fully discussed in *U. S. Public Health Service Bulletin* No. **173.** With industrial wastes, the 1-day demand is seldom representative and may be misleading (lag due to seeding or lead due to immediate demand). The 5-day demand, on the whole, appears to bear the most definite relation to the values obtained over other periods of incubation. For that reason it is strongly recommended that this period of incubation be adopted whenever the examinations are restricted to a single interval.

In this connection it is suggested that valuable information may frequently be obtained by conducting a test over several periods of incubation and plotting the data so as to obtain a complete deoxygenation curve.

Temperature of Incubation

At 20° C. a variation in temperature of one degree causes a change of about 5 per cent in the specific rate of deoxygenation. Consistent results, therefore, will not be obtained unless the temperature of incubation is reasonably constant.

In selecting a temperature of incubation it is to be borne in mind that,

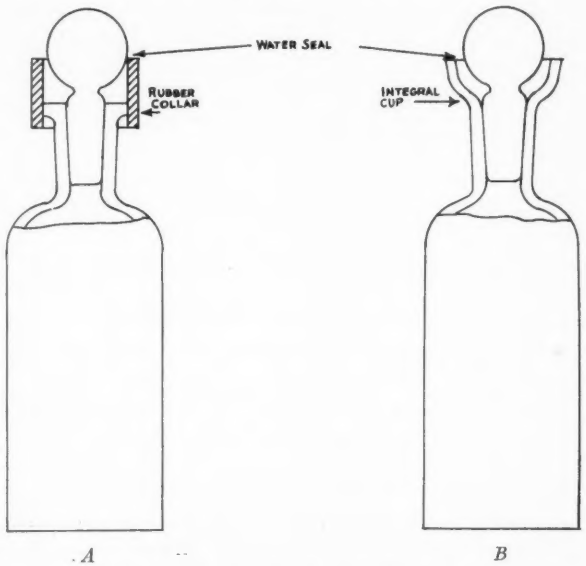

FIG. 3.—Incubation Bottles with Water Seals.

in equilibrium with air, water at 37° C. may contain less than 7.0 parts per million of dissolved oxygen, while at 20° C. the saturation value is 9.17 parts per million. Supersaturation and its attendant errors will therefore be encountered when a temperature of 37° C. is adopted. Moreover, the range of oxygen depletion is narrowed considerably when tests are conducted at 37° C. At low incubation temperatures, say, 10° C. or less, consistent results will not be obtained unless the temperature of the samples as collected was also low. For these reasons a temperature of incubation of 20° C. is recommended.

Blanks

A correction obviously must be applied if the dilution water itself has an appreciable oxygen demand.

If stored natural water has been used for dilution, it may be assumed that it still has a measurable demand even after storage. To determine its magnitude, bottles of the same size as those used for the dilutions are filled with the dilution water, rinsing the siphon before use to avoid contamination. These blanks are incubated along with the diluted subsamples.

If a synthetic dilution water consisting of distilled water with added mineral salts is used, its oxygen demand may be so small as to be negligible in ordinary work. In any event, when the 5-day oxygen demand of a dilution water, synthetic or otherwise, is very small (0.05 p. p. m. or less), it is advisable to determine its magnitude by averaging a large number of 5-day determinations rather than to place complete reliance on any single determination. The average result obtained may then be used as a constant correction factor.

If more than one period of incubation is employed, the oxygen demand of the dilution water over the shorter periods of incubation may approach the experimental error. In such cases negative values may be obtained. Again the correction should be based on the more reliable results obtained over the longer periods of incubation, using conversion factors (cf. *Public Health Bulletin* No. **173**). Thus for bicarbonate distilled water with an average 10-day demand of 0.18 p. p. m., the correction applicable to 1-day results is about 0.04 p. p. m., a negligible figure in most work.

If a correction must be applied, it should be proportioned to the amount of dilution water present. Thus, if the concentration of waste in the diluted subsample is 50 per cent, the correction applied should be one-half of the value found for the dilution water.

If the concentrations are all less than 1 per cent, the correction may be considered equal to the oxygen demand of the dilution water and the same for all concentrations.

Bottles for incubation tests should be cleaned with concentrated sulphuric acid (or cleaning mixture) and thoroughly rinsed with tap water before use. Unless this precaution is taken, the oxygen demand values will be misleading.

Computation of Oxygen Demand

Given the initial and final oxygen content of a diluted sample over any period of time, the oxygen demand of the sample for that period is the corrected difference times a factor for the concentration of sample in the dilution. The concentration factor is the reciprocal of the concentration when expressed decimally. Thus for a five per cent concentration or,

decimally expressed, 0.05, the factor is 20. The following examples show the method of computation. All results are to be expressed in parts per million.

Conc. %	Burette Readings Initial	Final	Dissolved Oxygen Initial	Final	Depletion Observed	Corrected	Dilution Factor	B. O. D.
100	0.0		0.0					
0	8.7	8.6	8.7	8.6	0.1			
10	Computed	2.4	7.8	2.4	5.3	5.2	10	52
5	Computed	5.5	8.3	5.5	2.8	2.7	20	54

Conc. %	Burette Readings Initial	Final	Dissolved Oxygen Initial	Final	Depletion Observed	Corrected	Dilution Factor	B. O. D.
100	6.4	2.1	6.4	2.1	4.3		1	4.3
0	8.7	8.5	8.7	8.5	0.2			
50	Computed	5.2	7.5	5.2	2.3	2.2	2	4.4

NOTE: In the above examples, concentration refers to the percentage of sample in the diluted subsample. A 100 per cent concentration, obviously, refers to the original sample before dilution, while a 0 per cent concentration refers to the dilution water blank.

The form of data sheet as suggested by the examples follows that used by the United States Public Health Service. In the examples it is understood that a corrected 200-ml. sample was titrated with 0.025 N $Na_2S_2O_3$. If a different volume of sample or strength of thiosulphate were used, the columns for burette readings and dissolved oxygen content would show different entries.

The first example indicates the situation which arises when a sample containing no dissolved oxygen is diluted. The computed oxygen content of a 10 per cent concentration of such a sample is, then, 90 per cent of the oxygen content of the diluting water. The oxygen demand of the dilution water, as shown by the blank, is used as a correction because the concentration of sample is low.

The second example indicates the type of data obtained when a sample of low oxygen demand, and containing dissolved oxygen, is incubated with and without dilution. In this case, the oxygen content of a 50 per cent concentration is, obviously, equal to the sum of 50 per cent of the oxygen content of the sample, plus 50 per cent of the oxygen content of the dilution water. In this case, the correction for the oxygen demand of the blank is proportioned in accordance with the relative concentrations of sample and dilution water in the diluted subsample.

Determination of Dissolved Oxygen

See THIS JOURNAL, May, 1932, pages 413–427. The dissolved oxygen procedure as presented in the report of the Great Lakes and Ohio River Boards differs from this published procedure only in minor respects, as follows:

(1) In the standardization of the $Na_2S_2O_3$, iodine solution may be used in addition to biniodate and bichromate.

(2) Use of starch solutions preserved with zinc chloride or salicylic acid has been regarded as optional to freshly prepared starch solutions.

(3) Details on the titrations were omitted.

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Future Research

It is the opinion of the Committee that further studies should be conducted using the recommended uniform procedure for biochemical oxygen demand determinations with various kinds of sewages and trade wastes to ascertain whether it is desirable or necessary to use special modifications in the analytical technique with certain sewages or wastes. It is desired to arrive at limiting factors in such cases in order that modified uniform methods may be established to give most reliable data and to make it possible to secure comparable results between laboratories. This work is to be an extension of coöperative studies agreed upon at the meetings of June 28, 1930, and December 5–6, 1930, and information obtained is to be summarized for discussion at a future meeting of the Committee.

Research proposed for attention by committee members, includes:

(1) Biochemical oxygen demand determinations with nitrified or partly nitrified sewage effluents.

(2) Studies of biochemical oxygen demands obtained with chlorinated sewage; development of a procedure to dissipate chlorine and chloramine compounds.

(3) Studies to develop a method for determination of immediate oxygen demand, particularly with trade wastes.

(4) Studies to evaluate the effect of dissolved oxygen in reagents.

(5) Extension of biochemical oxygen demand studies to develop special methods, when necessary, for use with certain kinds of trade wastes.

In addition to the trade wastes outlined in the progress report under date of December 5–6, 1930, it is believed desirable to include certain trade wastes which are highly acid in nature, such as pickling liquors from steel mills, acid mine drainage and effluents from chemical manufacturing plants. Wastes that might have a toxic effect and thereby interfere with the biological oxidation process are also to be considered.

In carrying out these biochemical oxygen demand studies it is considered desirable that the pH of blanks and samples before and after dilution, also at the end of incubation periods, be determined and recorded.

All possible information or other characteristics of samples and dilution water used is to be obtained.

While it was agreed that this research would be conducted along with routine duties of committee members, experience has shown the need for definite time and financial provisions for the work. To expedite future committee activities it is recommended that the work be given special consideration in the preparation of programs and budgets for the departments and laboratories participating in the studies.

Members of Committee

C. R. Cox, New York	R. D. Scott, Ohio
F. E. Daniels, Pennsylvania	E. H. Parks, Indiana
*M. H. Coblentz, Maryland	*F. W. Kittrell, Tennessee
*R. H. Homewood, Virginia	H. A. Whittaker, Minnesota
*M. F. Trice, North Carolina	E. J. Theriault, U. S. Public Health Service
*L. K. Herndon, West Virginia	L. F. Warrick, Wisconsin (*Chairman*)

Reviewed and approved by the Committee on Methods of Sewage Analysis of the Federation of Sewage Works Associations.

Members of Committee

A. M. Buswell	F. W. Mohlman
W. D. Hatfield	W. Rudolfs
J. J. Hinman	E. J. Theriault (*Chairman*)

[*Editor's Note:* A large part of the text of this report has been taken verbatim from Supplement No. 90 of the U. S. Public Health Service, entitled "Detailed Instructions for the Performance of the Dissolved Oxygen and B. O. D. Tests," by Emery J. Theriault, issued in 1931. This bulletin may be obtained for 10 cents from the Superintendent of Documents, Washington, D. C.]

* Appointed to the committee in March, 1932, and consequently unable to participate in the work leading up to this report.

Heat and Energy Relations in the Digestion of Sewage Solids
IV. Measurement of Heat and Energy Interchange

BY GORDON M. FAIR AND EDWARD W. MOORE

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The measurement of heat and energy interchange in the process of sludge digestion seems, as yet, to have received little attention. Bach[1] reports a few figures, but a search of the literature reveals no other data. This is rather surprising in view of the practical importance of utilizing the power to be derived from the gases of decomposition. A good reason for this seeming neglect may be found, however, in the fact that application of thermodynamic laws to a process so complicated as sludge digestion, for which the exact physical and chemical mechanism is still unknown, often fails to yield results of value. In spite of this possibility, there comes a time when an attempt must be made to apply the principles of thermodynamics to a thermal process of economic significance—such as sludge digestion—if for no other reason than to point out the way for future investigations. The sooner this attempt is made to measure the heat changes accompanying the process, the better will be its prospects for both economic and scientific advancement.

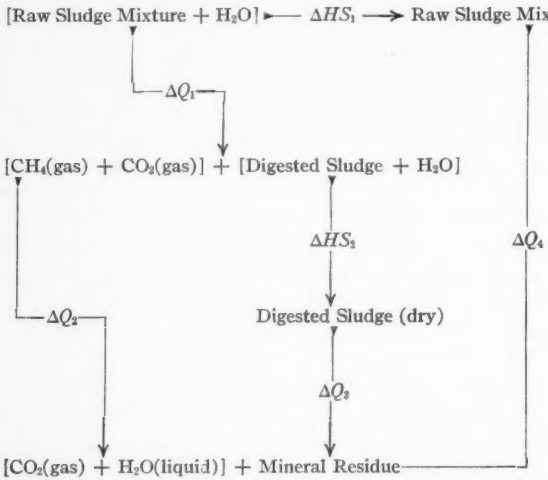
The preceding papers of this series[2,3,4] have described some of the findings of a group of digestion experiments carried out by the authors at temperatures ranging from 25–60° C. (77–140° F.) with both plain-sedimentation solids and activated sludge. In all of these experiments, the fuel values before and after digestion, and the quantity and kind of gases evolved were measured, with a view to establishing the heat balance of the process.

Outline of Thermal Balance.—The complete cycle which furnishes the basis for study may be outlined as in the accompanying diagram.

In this diagram ΔHS_1 and ΔHS_2 are the heats of solution of the undigested and digested sludges, respectively. ΔQ_2 is the heat of combustion of the CH_4 produced when burnt to gaseous CO_2 and liquid H_2O at 18° C. ΔQ_3 is the heat of combustion of the digested sludge when burnt to gaseous CO_2, liquid H_2O and mineral oxides, etc., in a bomb calorimeter. ΔQ_4 is the heat of combustion of the raw-sludge mixture when burnt to gaseous CO_2, liquid H_2O, mineral oxides, etc., in a bomb calorimeter. This leaves ΔQ_1 as the change in heat of combustion produced by the digestion process. This is sometimes called the "heat of reaction." It is not the true thermodynamic heat of reaction (see Lewis and Randall,[5] p. 147), but is the same quantity, in this case, as that called ΔH in the thermodynamic textbooks,

namely, the change in "heat-content" caused by the reaction. In accordance with the convention of Lewis and Randall regarding ΔH, ΔQ_1 will be taken as a positive quantity when the system gains heat of combustion, and as a negative quantity when it loses heat of combustion.

The heats of solution ΔHS_1 and ΔHS_2, must remain unknown quantities as long as the exact composition of the material in solution is not determined. However, heats of solution are generally small in comparison with heats of combustion, and it is probable that the heats of solution exert little effect on the cycle. They are also opposite in sign, though not equal



in magnitude, and should offset each other to a large extent. Neglecting the heats of solution, we may set up the following balance:

$$\Delta Q_1 = \Delta Q_2 + \Delta Q_3 - \Delta Q_4$$

Experimental Results.—If the quantities ΔQ_2, ΔQ_3 and ΔQ_4 have been determined, ΔQ_1 may be found by computation. The results obtained by the authors are set forth in Table I. The heat quantities are given as kilogram calories for the total amount of dry sludge used in the experiments and the heat of combustion of CH_4 was taken from International Critical Tables at 210.8 kilogram calories per gram molecule (24.0 liters at 20° C. and 760 mm. pressure.)

The figures published by Bach[1] are summarized in Table II.

An inspection of the results presented in these tabulations will show that both negative and positive values of ΔQ_1 are encountered. While Bach attributes the finding of a positive ΔQ_1 to a disagreement between the heat quantity calculated from the gas analysis and the actual heating value of

the gas, the authors hope to demonstrate that there is no reason why ΔQ_1 should not be positive as well as negative. Accepting the values of ΔQ_1 as found, it appears that the digestion process may be either exothermic or endothermic, depending on conditions. Since positive values of ΔQ_1 are generally associated in the authors' studies[3] with rapid digestion of the sewage solids, it may be assumed for sake of discussion that the main processes involved are potentially endothermic, and that the highest thermodynamic efficiency is attained when digestion proceeds essentially as an endothermic reaction. When heat or energy losses occur during digestion the process may become exothermic. These losses are caused conceivably by reactions that are apart from the main reactions of digestion, or by inefficiency in the progress of the main reaction.

Thermodynamic Efficiency of Digestion.—The "thermodynamic efficiency" of digestion is correlated roughly with the conditions of the authors' experiments. In order to appreciate this fact it should be stated that the raw solids of Series I were seeded with sludge produced at a temperature lower than the temperature of incubation, while the remaining series were incubated after seeding them with the residues produced at like temperature in the preceding series, except in the case of Series VII, in which all of the sludges were incubated at 50° C. It should also be noted that, so far as Series IV and in part V, as well as VI, are concerned,

TABLE I

CHANGE IN HEAT CONTENT OF SEWAGE SLUDGE BY DIGESTION

Series and Origin of Raw Solids	Temp. of Digestion, ° C.	Fuel Value of Charge, ΔQ_4	Fuel Value of Residue After Digestion, ΔQ_3	Fuel Value of Gas, ΔQ_2	Mols of Gas Produced: Methane	Mols of Gas Produced: Carbon Dioxide	Change in Heat Content: Total ΔQ_1	Change in Heat Content: Per Cent $\frac{\Delta Q_1}{\Delta Q_4} \times 100$
I	25	465.0	152.0	212.0	1.005	0.473	−101.0	−21.7
Plain	30	465.0	194.8	229.8	1.090	0.504	−40.4	− 8.7
Sedimentation	35	465.0	199.6	226.0	1.072	0.482	−39.4	− 8.5
Solids	40	465.0	225.6	225.0	1.067	0.487	−14.4	− 3.1
	45	465.0	225.6	199.5	0.947	0.442	−39.9	− 8.6
	50	465.0	246.4	210.0	0.996	0.446	− 8.6	− 1.9
	60	465.0	175.0	190.0	0.902	0.406	−100.0	−21.5
II	25	171.0	129.1	67.6	0.321	0.161	+25.7	+15.0
Plain	30	192.4	138.0	62.2	0.295	0.152	+ 7.8	+ 4.1
Sedimentation	35	194.8	126.5	61.1	0.290	0.143	− 7.2	− 3.7
Solids	40	207.8	117.0	64.1	0.304	0.156	+26.7	−12.8
	45	207.8	127.5	68.7	0.326	0.165	−11.6	− 5.6
	50	218.2	138.0	69.6	0.330	0.165	−10.6	− 4.9
III	25	164.8	77.4	105.3	0.500	0.241	+17.9	+10.9
Plain	30	167.5	78.8	104.5	0.496	0.246	+15.8	+ 9.4
Sedimentation	35	167.9	98.2	105.3	0.500	0.250	+35.6	+21.2
Solids	40	164.8	98.6	112.9	0.536	0.250	+46.7	+28.3
	45	165.1	88.8	109.0	0.518	0.259	+32.7	+19.8
	50	164.5	82.4	122.1	0.580	0.281	+40.0	+24.3

TABLE I—*Continued*

CHANGE IN HEAT CONTENT OF SEWAGE SLUDGE BY DIGESTION

Series and Origin of Raw Solids	Temp. of Digestion, ° C.	Fuel Value of: Charge, ΔQ_4	Fuel Value of: Residue After Digestion, ΔQ_3	Gas, ΔQ_2	Mols of Gas Produced: Methane	Mols of Gas Produced: Carbon Dioxide	Change in Heat Content: Total ΔQ_1	Change in Heat Content: Per Cent $\frac{\Delta Q_1}{\Delta Q_4} \times 100$
IV	25	141.0	104.0	26.1	0.124	0.041	−10.9	− 7.7
Activated	30	142.1	91.1	27.2	0.129	0.048	−23.8	−16.7
Sludge	35	162.6	122.0	33.7	0.160	0.062	− 6.9	− 4.2
	40	161.9	120.5	35.2	0.167	0.067	− 6.3	− 3.8
	45	153.4	118.4	37.9	0.180	0.072	+ 2.9	− 1.9
	50	145.0	99.6	38.8	0.184	0.077	− 6.6	− 4.6
	60	215.3	165.0	66.4	0.315	0.149	+16.1	− 7.5
V	25	140.5	104.0	19.4	0.092	0.030	−17.1	−12.2
Activated	30	136.5	103.0	23.8	0.113	0.040	− 9.7	− 7.1
Sludge	35	151.5	116.5	21.1	0.100	0.033	−13.9	− 9.2
	40	151.1	114.5	23.2	0.110	0.042	−13.4	− 9.0
	45	150.0	99.2	35.4	0.168	0.064	−15.4	−10.2
	50	139.1	95.0	32.0	0.152	0.063	−12.1	− 8.7
	60	170.7	103.0	38.6	0.183	0.082	−29.1	−17.1
VI	25	155.5	87.3	86.6	0.411	0.210	+18.4	+11.8
Plain	30	187.0	74.1	102.6	0.487	0.246	−10.3	− 5.5
Sedimentation	35	200.0	100.0	95.1	0.451	0.228	− 4.9	− 2.5
Solids	40	187.0	95.4	100.7	0.478	0.241	+ 9.1	+ 4.9
	45	205.0	88.5	81.0	0.384	0.197	−35.5	−17.3
	50	195.5	67.8	107.2	0.509	0.277	−20.5	−10.5
	60	216.3	115.0	110.0	0.527	0.295	+ 8.7	+ 4.0
VII	(25) 50	187.0	96.7	87.7	0.416	0.214	− 2.6	− 1.4
Plain	(30) 50	189.0	133.0	100.9	0.479	0.238	+44.9	+23.8
Sedimentation	(35) 50	209.0	115.5	92.3	0.438	0.223	− 1.2	− 0.6
Solids	(40) 50	204.0	118.4	95.5	0.453	0.228	+ 9.9	+ 4.9
	(45) 50	197.7	136.8	98.8	0.469	0.236	+37.9	+19.2
	(50) 50	179.0	92.2	92.8	0.440	0.224	+ 6.0	+ 3.4
	(60) 50	228.5	114.5	109.5	0.520	0.255	− 4.5	− 2.0

the seeding material did not originate from the same kind of sewage treatment process, and that it was qualitatively different in composition.

A study of the authors' findings shows the following: Series I, seeded with sludge not produced at the temperatures of digestion exhibits considerable thermal inefficiency. Series II is generally less inefficient and manifests marked efficiency at the lower temperatures, indicating, as would

TABLE II

CHANGE IN HEAT CONTENT OF DIGESTING SLUDGE REPORTED BY BACH

Source of Sludge	Fuel Value of: Charge, ΔQ_4	Fuel Value of: Residue After Digestion, ΔQ_3	Gas, ΔQ_2	Change in Heat Content, ΔQ_1
Essen Nord	96.9	72.29	20.94	− 3.67
Essen-Frohnhausen	85.08	36.46	69.73	+21.11
Essen Nord-West	142.49	42.15	102.85	+ 2.51
Oberhausen	101.30	35.78	56.47	− 9.05

be expected, that proper seeding material has been established first at temperatures nearest those at which the original seeding material was produced (about 20° C.). The high efficiency of Series III indicates full establishment of proper seeding conditions at all temperatures. Series IV exhibits a decreasing degree of efficiency, since the raw solids originate in activated sludge, a material difficult to digest. Series V is even less efficient than IV, indicating a closer approach to a true activated-sludge digestion, the seeding material being fundamentally digested activated sludge, not digested plain-sedimentation solids, as in Series IV. Series VI shows a return of efficiency in some cases, the raw material once more being plain-sedimentation solids. Series VII reëstablishes an even higher degree of efficiency, as the seeding material has become more active after having passed through a stage of fresh-solids digestion in Series VI.

The great variation in the thermodynamic efficiency of the process becomes apparent from the wide range of ΔQ_1. Expressed as a percentage of the fuel value of the original charge (ΔQ_4), ΔQ_1 varies from a 21.7 per cent loss of that fuel value (Series I, 25° C.) to a 28.3 per cent gain over it (Series III, 40° C.). While there appears to be no well-marked relationship between the magnitude of ΔQ_1 and the temperature of incubation, larger values of ΔQ_1 generally prevail at the higher temperatures. It is probable that existing temperature relationships are obscured in part by small variations in seeding conditions since consistent increase of ΔQ_1 with temperature might normally be expected. The reason for this is that endothermic reactions become more complete the higher the temperature.

Sources of Error.—In a study such as this it is essential that the sources of possible errors in experimental data be examined closely before theoretical thermodynamics are applied to them. As far as direct experimental errors are concerned, the authors feel that these have been eliminated to the fullest extent allowed by the nature of the material under study. The determinations of percentage solids and fuel value per gram of solids, on which part of the heat balance is based, were duplicated to avoid sampling errors. The duplicate results were rarely more than 1 to 2 per cent apart. The gas analyses, which furnished the remainder of the heat balance, were carried out in the most advanced type of Orsat apparatus, employing combustion over copper oxide at 300° C. for any hydrogen present, and slow combustion by a hot platinum wire for methane. The amount of hydrogen found was negligible. Since the volume of the manifold was determined, the apparatus did not give slightly high results for combustible gas, as is usually the case in the Orsat type of equipment.

There is another source of error which might influence the result. Heukelekian[6] and Buswell[7] have shown that volatile materials in considerable quantity, including organic acids, ammonium oxalate and carbonate, indole, skatole, amines and ammonia, are lost in drying sewage sludge and

do not appear in the "total solids" determination. The fuel value of these compounds would, therefore, be lost in determining the heats of combustion of the raw and digested sludges, while the energy of the compounds might be utilized in the digestion process proper. The magnitude of the error thus introduced in the determination of ΔQ_1 would depend on the relative amounts of these volatile substances present in the raw and digested materials. If a much larger quantity of such material was present in the raw than in the digested sludge, the observed ΔQ_1 would become greater than its true value, and this might account for the occurrence of positive values of ΔQ_1. If relatively more volatile compounds were present in the digested sludge, the reverse would be true, and the observed ΔQ_1 would be low. According to Heukelekian's work, it is the latter condition which generally prevails. The positive values of ΔQ_1, therefore, probably cannot be attributed to this type of error. In fact, if much so-called liquefaction has taken place during digestion, an experiment, which should yield a positive ΔQ_1, might show a negative value.

Concepts of Heat and Energy Content.—There appears to be no theoretical reason why the value of ΔQ_1 should not be positive as well as negative. The heat of combustion of a substance is not a complete measure of its energy, or work-producing power; so there can be no question of a violation of the law of the conservation of energy. Combustion and other chemical processes taking place under similar conditions are highly irreversible, *i. e.*, they waste a large portion of the energy content of the material, and this portion wasted is not obtained even as heat. To make this clearer, we may borrow an example from Lewis and Randall[5] (p. 171).

The reaction: $C + {}^1/_2O_2 = CO$, if allowed to occur in a calorimeter, yields heat to the extent of 26,150 cal. for 12 g. of carbon. But if this reaction took place in a perfectly reversible electric cell, in a thermostat, and working against an opposing potential infinitesimally less than its own, it would do work to the extent of 32,510 cal., absorbing 6360 cal. from the thermostat. This work might be applied to the reduction of CO_2 in another reversible cell, by the reaction: $CO_2 = CO + {}^1/_2O_2$, which requires 61,750 cal. of work per mol of CO_2. The amount of CO produced would be $32{,}510 \div 61{,}750 = 0.5265$ mol, and the reaction would absorb $0.527 \times 6350 = 3340$ cal. from the surroundings. There would then exist 1.5265 mols of CO, with a heat of combustion of 103,950 cal., as a product of the original 1 mol of carbon, whose heat of combustion was 94,250 cal. The net gain is 9700 cal. equal to the heat absorbed in the two cycles of the process. The work-producing power of the 1.5265 mols of CO is still the same as that of the 1 mol of carbon, *viz.*, 94,250 cal. Hence, by using the work-producing power of the carbon as efficiently as possible, there has been a gain in heat-producing power at the expense of the surroundings, through the agency of

a system of reactions which runs spontaneously. No violation of the law of the conservation of energy is involved.

The authors intend to show that the same type of process may, and seemingly does occur in anaerobic sludge digestion. The process outlined above, having 100 per cent thermodynamic efficiency, naturally requires infinite time for completion as compared with the practically instantaneous process of combustion of carbon. But the process of sludge digestion is also a protracted one and for this reason presumably has a high thermodynamic efficiency.

It may be useful at this point to introduce a few other terms employed in thermal chemistry. For any given chemical reaction, ΔH, the change in heat content, is the heat absorbed by the reaction when it runs irreversibly in a calorimeter. On the other hand, ΔF, the so-called free energy, is the maximum work obtainable from the reaction when it runs reversibly, as in a perfect electric cell operating against a potential infinitesimally less than its own, and thus requiring infinite time for completion. The quantity ΔF is taken as negative if the reaction does work, in which case the reaction will run spontaneously. If ΔF is positive, the reaction will require work to be expended on it, or it will not run. Frequently ΔH and ΔF possess the same sign and are alike in magnitude; but they may differ greatly in magnitude, and even in sign. The terms ΔH and ΔF are used by Lewis and Randall.[5] To describe the gain or loss in heat of combustion experienced in a cycle such as the one just outlined, we may introduce another term of our own. This term we will call ΔQ_1. Its magnitude depends on the relationship of the ΔF's and ΔH's in the reactions making up the cycle, and will serve as a measure of the heat absorbed by the cycle.

Sludge Digestion, a Thermodynamic Cycle.—We may consider the sludge-digestion process as a thermodynamic cycle of the type just illustrated. Instead of the electric cells, we have a host of microörganisms effecting the primary reactions, and utilizing the energy thereby liberated for other reactions of the second type, such as the synthesis of the complex organic compounds making up their own structure, and for similar reactions necessary to their life processes. The thermodynamic efficiency involved, however, is not 100 per cent, like that of the electric cells. The primary reactions correspond to the oxidation of the original carbon, the secondary ones to the reduction of the CO_2, the former yielding energy, the latter requiring it. The methane, which is one of the products of digestion, is analogous to the CO, in that the ΔH of oxidation is greater than the ΔF as follows:

$$CH_4\ (1\ \text{atm.}) + 2O_2\ (1\ \text{atm.}) = CO_2\ (1\ \text{atm.}) + H_2O\ (\text{liq.})$$

From this equation $\Delta F_{298} = -194{,}600$ and $\Delta H_{298} = -212{,}600$ cal. As is readily seen from the example, the best chance of obtaining a positive

ΔQ_1 is by utilizing reactions in which ΔH and ΔF are as widely different as possible. On this basis we may proceed to examine some of the reactions which take place in the sludge-digestion process, to see if they are of this type. The difficulty of such an examination, however, must not be underestimated.

Thermochemical Reactions in Sludge Digestion.—The reactions involved in the sludge-digestion process are highly complex, and there are many possible mechanisms. Furthermore, thermodynamic information relative to the more complex organic compounds is scarce. It is possible, therefore, to treat thermodynamically only a few of the reactions that have been suggested by different workers.

It has been established that a large proportion of the yield of methane during sludge digestion has its source in the degradation of fatty acids derived from the greases and soaps of sludge, and that this gas is produced probably also as a decomposition product of the proteins.

Buswell and Neave[8] (pp. 66–67) have offered a mechanism of oxidation by water which furnishes a highly satisfactory explanation of the degradation of fatty acids. Taking propionic acid as an example, they write the reaction as effected by the bacteria as follows:

$$4C_3H_6O_2\ (\text{soln.}) + H_2O\ (\text{liq.}) = 5H_2CO_3\ (\text{soln.}) + 7CH_4\ (\text{soln.}) \qquad (1)$$

For the reaction in this form $\Delta H = -20$ kg. cal., *i. e.*, that amount of heat is given off in the course of the reaction.

The same reaction as dealt with by the engineer reads as follows:

$$4C_3H_6O_2\,(\text{soln.}) + 2H_2O\,(\text{liq.}) = 5CO_2\,(\text{gas } {}^1/_3\,\text{atm.}) + 7CH_4\,(\text{gas } {}^2/_3\,\text{atm.}) \qquad (2)$$

The gas pressures represent an average of the total gas evolved during a digestion experiment, and may vary considerably from time to time. Neglecting the heat of solution of propionic acid, which according to Buswell is small, the ΔH of this reaction may be computed by considering the following thermochemical equations:

$$4C_3H_6O_2 + 28O \longrightarrow 12CO_2 + 12H_2O + a \text{ kg. cal.} \qquad (3)$$

$$7CH_4 + 28O \longrightarrow 7CO_2 + 12H_2O + b \text{ kg. cal.} \qquad (4)$$

$$4C_3H_6O_2 - 7CH_4 \longrightarrow 5CO_2 - 2H_2O + (a - b) \text{ kg. cal.} \qquad (5a)$$

or

$$4C_3H_6O_2 + 2H_2O = 5CO_2 + 7CH_4 + (a - b) \text{ kg. cal.} \qquad (5b)$$

Here $\Delta H = -(a - b)$ is the heat of combustion of the acid minus that of the methane. This reaction will be found to be endothermic, *i. e.*, ΔH is positive. The difference between it and the reaction for the dissolved constituents lies in the large quantity of heat absorbed from the surroundings in the breaking down of H_2CO_3 and dissolution of methane.

Buswell and Neave[8] give a general formula for the anaerobic oxidation of the fatty acids as follows:

$$C_nH_{2n}O_2 + \frac{(n-2)}{2} H_2O = \frac{(n+2)}{4} CO_2 + \frac{(3n-2)}{4} CH_4 \qquad (6)$$

As a check on the thermodynamic possibility of the reaction for each acid they use ΔH computed on the basis of reaction type (1), taking this as the energy available for the bacteria. The actual energy available is ΔF; but in a great many cases $\Delta H \approx \Delta F$ approximately, and may quite justifiably be assumed so to be where no free energy data are available. It has been shown, however, that to obtain a positive ΔQ_1, the ΔH and ΔF must be considerably different, and it appears from the data available, that this is true of anaerobic oxidations. For example in the alcohol reaction: $C_6H_{12}O_6 = 2C_2H_5OH + 2CO_2$, $\Delta H_{298} = -31.2$ kg. cal., and $\Delta F_{298} = -55.4$ kg. cal., which is a considerable difference. The same thing is true to an even greater extent for the type of reaction proposed by Buswell and Neave. Table III shows a comparison of the values for the reactions of a number of fatty acids. Here $\Delta H'$ refers to the heat of reaction for reaction type (1), and is taken from Buswell's[8] work, while ΔH is the heat of reaction of reaction type (2). On the other hand, ΔF, the free-energy change, is the same for both types of reactions, since the decomposition of H_2CO_3 and dissolution of CH_4 are equilibrium changes, for which $\Delta F = 0$. The values of ΔH and ΔF are for a temperature of 25° C. or 298° absolute. In this tabulation all quantities $\Delta H'$, ΔH and ΔF are in kilogram calories absorbed per gram molecule of the fatty acid reacting. The concentration of the fatty acid is assumed to be 0.1 molal except where its saturated solution contains less than 0.1 mol, in which case a saturated solution is used. The first reaction is the over-all reaction from dissolved solid to gas. The gas pressures assumed are: $^1/_3$ atmosphere for CO_2 and $^2/_3$ atmosphere for CH_4, corresponding to the average composition of the gas evolved in a digestion experiment. The second reaction which the bacteria carry through is of the type given by Buswell. The concentration of the acid is taken to be the same as before, and the concentrations of H_2CO_3 and dissolved CH_4 are assumed to be such as to be in equilibrium with the gas pressures previously given, so that ΔF is the same for both reactions. Buswell[8] does not state the concentrations used in his calculations, but merely defines them as dilute solutions. The solutions assumed by the authors come well within Buswell's definition. Since, furthermore, the change induced in the heat of reaction by large changes in concentration is very small, we believe Buswell's figures will apply without serious error.

The values of $\Delta H'$ are taken from Buswell and Neave[8] (p. 66). A check on the figures given shows that they are not, as stated, in kilogram calories

TABLE III

HEAT AND ENERGY CHANGES ASSOCIATED WITH THE DECOMPOSITION OF FATTY ACIDS

Acid	Reactions	$\Delta H'$, Kg. Cal.	ΔH_{298}, Kg. Cal.	ΔF_{298}, Kg. Cal.
Formic [Soln. 0.1 n]	$4HCOOH = 3CO_2 + CH_4 + 2H_2O$	..	−10	−13.4
	$4HCOOH = 3H_2CO_3 + CH_4$ (soln.)	−14	.....	−13.4
Acetic [Soln. 0.1 n]	$CH_3COOH = CO_2 + CH_4$	..	+1.8 or +4.1	− 8 or −18
	$CH_3COOH + H_2O = H_2CO_3 + CH_4$	− 3	.....	− 8 or −18
Propionic [Soln. 0.1 n]	$4CH_3CH_2COOH + 2H_2O = 5CO_2 + 7CH_4$	..	+ 5	[−18]
	$4CH_3CH_2COOH + 7H_2O = 5H_2CO_3 + 7CH_4$	− 5	.....	[−18]
n-Butyric [Soln. 0.1 n]	$2CH_3[CH_2]_2COOH + 2H_2O = 3CO_2 + 5CH_4$	..	+ 7	[−23]
	$2CH_3[CH_2]_2COOH + 5H_2O = 3H_2CO_3 + 5CH_4$	− 4	.....	[−23]
n-Valeric [Soln. 0.1 n]	$4CH_3[CH_2]_3COOH + 6H_2O = 7CO_2 + 13CH_4$	..	+ 6	[−30]
	$4CH_3[CH_2]_3COOH + 13H_2O = 7H_2CO_3 + 13CH_4$	− 7	.....	[−30]
Palmitic [Satd. Soln.]	$2CH_3[CH_2]_{14}COOH + 14H_2O = 9CO_2 + 23CH_4$	..	+44	−92
	$2CH_3[CH_2]_{14}COOH + 23H_2O = 9H_2CO_3 + 23CH_4$	+ 4	.....	−92
Stearic [Satd. Soln.]	$CH_3[CH_2]_{16}COOH + 8H_2O = 5CO_2 + 13CH_4$	..	+42	[−99]
	$CH_3[CH_2]_{16}COOH + 13H_2O = 5H_2CO_3 + 13CH_4$	− 3	.....	[−99]

per mol acid, but in kilogram calories for the entire reaction. We have merely reduced them to kilogram calories per mol acid reacting by dividing by the number of mols of acid entering into the reaction.

The value of ΔH per mol acid reacting is computed for the over-all reaction by the method illustrated previously in this paper, the method being extended to cover the reaction involving the dissolved acid by deducting its heat of solution from its heat of combustion. The heats of combustion are taken from the International Critical Tables (V, p. 162), as are those of solution (V, pp. 148 and 159). The heats of solution at infinite dilution are used, as this is the closest approximation to $0.1n$ that can be obtained. Even where no heat of solution is available (butyric, valeric, palmitic and stearic acids) the uncertainty introduced is probably less than 1 kilogram calorie per mol acid. For the heat of combustion of CH_4 that at atmospheric pressure is employed, since the heat content of a perfect gas is independent of its pressure, and the deviations from this law

are slight for any pressures under consideration. For example, Lewis and Randall (p. 100) give $\Delta H = -.335$ kg. cal. for O_2 (gas, 1 atmos.) $\longrightarrow$ O_2 (gas 200 atmos.).

The standard free energy values for the computation of ΔF^* (temp. 25° C., 298° abs.) are derived from two sources. Those for H_2O, CO_2, CH_4 are taken from the International Critical Tables (VII, p. 224), those for the gases being corrected to the pressures used by the formula $F = F^\circ + RT \log_e P$ (Lewis and Randall, p. 165). The values for the fatty acids and other organic compounds are derived from the work of Parks and coworkers;[9] some of them also appear in Buchanan and Fulmer:[10] "Physiology and Biochemistry of Bacteria." Parks and Kelley conclude from the series that the values of F°_{298} (kg. cal.) are as follows:

Methyl Alcohol	CH_3OH	−44,500
Ethyl Alcohol	CH_3CH_2OH	−44,000
n-Butyl Alcohol	$CH_3CH_2CH_2CH_2OH$	−44,100

and that the addition of CH_2 groups in an homologous series of organic compounds does not change their standard free energy. They then give the following values of F°_{298} (kg. cal.):

Acetic Acid	CH_3COOH	−96,600 or −87,000
Palmitic Acid	$CH_3[CH_2]_{14}COOH$	−89,000

The two divergent values for acetic acid are due to two values for its heat of combustion, the first that of Berthelot, the second that of Thomson. If we follow these authorities in making the least favorable assumption, *i. e.*, that the first value for acetic acid is correct, we may for purposes of approximation set F°_{298} for the other members of the series at −93,000. The values so derived are bracketed in the preceding tabulation, and conform well to the indicated trend. The value for formic acid, which is not a true member of the series in its behavior, has been independently determined (Lewis and Randall, p. 579). The free energy of dilution for this compound is also given in the same place, so its standard free energy at the required concentration is known. The free energy in solution for the other compounds is calculated from the pure substance or saturated solution by the equation $F_c' = F_c - RT \log_e \frac{[c]}{[c']}$ where c is the concentration of the pure liquid or saturated solution in mols per liter, and c' the concentration of the solution whose standard free energy is desired. This, of course, involves an entirely unjustified expansion of the laws of perfect solutions, but a comparison with the known value for formic acid indicates that the uncertainty is about 2 kg. cal. per mol acid. It decreases, furthermore, with the solubility of the acid, becoming almost nil, for example,

* The value of ΔF is also per mol acid reacting.

in the case of palmitic acid. Hence, the uncertainty introduced is probably less, in most cases, than the uncertainty in the standard free energy of the pure acid.

Many other reactions have been proposed for anaerobic degradation. A few of these may be examined thermodynamically, with the aid of the free energy values in our possession. Buswell and Neave[8] (pp. 64–65) propose five types, of which we may examine examples of four. The *d*-glucose, which appears as the primary reactant, will be taken at a concentration of 0.1 molal, at which its standard free energy (25° C.) is −221 kg. cal. approximately.

$$C_6H_{12}O_6\ (0.1M) = 3CH_4\ (^2/_3\ \text{atm.}) + 3CO_2\ (^1/_3\ \text{atm.}) \qquad \text{(I)}$$

From this equation $\Delta F_{298} = -103$ and $\Delta H = -41$ kg. cal. and the reaction would obviously furnish much energy.

$$C_6H_{12}O_6\,(0.1M) = CH_3CH_2CH_2COOH\,(0.1M) + 2CO_3\,(^1/_3\ \text{atm.}) + 2H_2\,(0.01\ \text{atm.}) \qquad \text{(II)}$$

Here $\Delta F_{298} = -67.0$ kg. cal. Neglecting the correction in the heat of combustion of hydrogen from 1 atm. to 0.01 atm. which, as already shown, is small, $\Delta H = -16.2$ kg. cal. Hydrogen is taken at 0.01 atm. because the gas in our experiments always showed less than 1 per cent H_2.

$$C_6H_{12}O_6\,(0.1M) + 6H_2O = 6CO_2\,(^1/_3\ \text{atm.}) + 12H_2\,(0.01\ \text{atm.}) \qquad \text{(III)}$$

From this equation $\Delta F_{298} = -41.0$ and $\Delta H = +147.8$ kg. cal.

$$2C_6H_{12}O_6\ (0.1\ M) + 3H_2O = 3C_2H_5OH\ (0.1M) + 6HCOOH\ (0.1M) \qquad \text{(IV)}$$

Here $\Delta F_{298} = -65.0$ and $\Delta H = +6.7$ kg. cal.

Bach[11] has also suggested several reactions; among them the following: $4H_2 + CO_2 = CH_4 + 2H_2O$. This reaction is thermodynamically possible at hydrogen pressures down to 10^{-5} atmospheres. Hence, failure to detect hydrogen in the gas evolved does not preclude its occurrence. At H_2O (0.01 atm.), $\Delta F_{298} = -20.3$ and $\Delta H = -62.8$ kg. cal.

Discussion of Results.—We have shown in the illustration given in the first part of this paper that in order to obtain a positive ΔQ_1, we must make use, in the first stage of the cycle, of a reaction in which the work produced $(-\Delta F)$ is greater than the heat produced $(-\Delta H)$. We have found this to be true for the majority of proposed reactions examined. If these reactions run reversibly, that is, with 100 per cent thermodynamic efficiency, the heat absorbed is $\Delta H - \Delta F$, and by comparing this with the figures already given, we may see that most of them absorb considerable heat. The efficiency, of course, is never 100 per cent. Although the subject has not been widely studied, the generally accepted belief is that the thermodynamic efficiency of bacteria is no higher than that of other living

things. Under normal conditions, therefore, a reaction such as the stearic acid reaction would only absorb some fraction of the 131 kg. cal. per mol of acid that it is theoretically capable of absorbing.

If now, we attempt to account for the observed magnitudes of ΔQ_1 in terms of gas-producing reactions, such as those of the fatty acids, or Buswell's Reaction I, and in terms of observed gas production, we find we cannot do so. For even at 100 per cent efficiency the maximum heat absorbed per mol of methane evolved is calculated to be about 20 kg. cal. (acetic acid reaction, or Buswell's Reaction I), whereas the observed values run as high as 47 kg. cal. absorbed for somewhat over $^1/_2$ mol methane evolved (Series III, 40° C.). This does not force us to the conclusion, however, that the observed values are wrong or impossible.

The first reason why the observed values of ΔQ_1 are believed to be consistent can readily be seen by studying the simplified example given previously. We have only considered the first half, or degradation, of the cycle in which the free energy is evolved. The second half, or partial resynthesis, in which the free energy is utilized, remains undiscussed. In the actual digestion process, this second portion corresponds to the utilization by the bacteria of the free energy available for various syntheses, such as the synthesis of their own protoplasm. The cycle may then repeat itself at a lower energy level in the degradation of the protoplasm of the dead bacteria. Of these synthetic reactions we know little. They may well be of the type of the second half of our illustrative cycle, in which the ΔF is less than ΔH, both being positive quantities in this case. The synthesis, furthermore, may cause absorption of heat, and raise ΔQ_1 still further.

The second reason why the observed values of ΔQ_1 are considered to be correct is that not all of the reactions of anaerobic sludge digestion produce gas. There may be, and probably are, many reactions of a type similar to Buswell's Reaction IV. This reaction, producing no gas, absorbs some 36 kg. cal. for each mol of glucose reacting. The products of such reactions may be stabilized in the sludge remaining after digestion by combination with other substances in it. Gas production, although it may represent the progress of digestion, is by no means the whole of digestion. Much heat may be absorbed by the non-gas producing reactions, of which we now have no definite knowledge. Some of these reactions may be concerned in the extensive recombination of nitrogen which Buswell and Neave[8] note. This only requires that the products of the remobilization have a lower free-energy content, but a higher heat content than the reactants.

Summary and Conclusions

In view of the foregoing considerations, the authors believe that there is no theoretical reason why ΔQ_1 should not be positive. The practical

evaluation of the gain that can thus be made with a given sludge must await more thorough knowledge of the reactions occurring in digestion. In view of this lack of information, and the complexity of the changes involved, such thermodynamic considerations as are given in this paper may do no more than serve as a guide to the actual facts.

The authors' findings may be summarized as follows:

1. A balance struck on the initial charge and final products of the digestion process shows that there may be a considerable increase in the heat of combustion of the products of digestion over that of the original charge of sludge.

2. This increase appears to occur more frequently when the seeding of the mixture is good.

3. A simple thermodynamic illustration seemingly indicates that there is no theoretical basis for denying this increase.

4. Thermodynamic treatment of the reactions proposed for sludge digestion by various authors points to the fact that most of them are of a type that would show such an increase.

Addendum

After the manuscript for this paper was completed, there appeared in THIS JOURNAL articles by Rudolfs[12] and Buswell and Boruff,[13] dealing with gas yields in their relation to volatile matter consumed in the digestion process. Since this question is somewhat related to the subject matter of this paper and since our tests included determinations which permit striking a balance between gas yields and volatile matter consumed, our

TABLE IV

YIELD OF GAS PER UNIT WEIGHT OF VOLATILE MATTER DESTROYED

Series	Temp. of Digestion, ° C.	Volatile Matter Destroyed, Grams	CH_4 Produced, Grams	CO_2 Produced, Grams	Weight of Gas Produced per Unit Weight of Volatile Matter Destroyed
I	25	38.6	16.1	20.8	0.96
Fresh Solids	30	33.6	17.5	22.2	1.18
Seeding Poor	35	35.6	17.2	21.2	1.08
	40	30.2	17.1	21.4	1.28
	45	30.0	15.2	19.4	1.15
	50	26.2	16.0	19.6	1.36
	60	26.4	14.5	17.9	1.23
II	25	9.8	5.14	7.08	1.25
Fresh Solids	30	9.1	4.73	6.69	1.26
Seeding Good	35	10.1	4.65	6.29	1.08
	40	13.1	4.87	6.86	0.90
	45	11.8	5.23	7.26	1.06
	50	11.5	5.29	7.26	1.09

TABLE IV—*Continued*

III	25	12.8	8.02	10.60	1.45
Fresh Solids	30	12.8	7.95	10.82	1.47
Seeding Good	35	12.9	8.02	11.00	1.47
	40	10.0	8.59	11.00	1.96
	45	10.7	8.30	11.40	1.84
	50	12.8	9.30	12.36	1.69
VI	25	12.0	6.59	9.24	1.32
Fresh Solids	30	14.1	7.81	10.82	1.32
Seeding Poor	35	14.3	7.23	10.03	1.21
	40	13.4	7.66	10.60	1.36
	45	14.1	6.16	8.67	1.05
	50	13.6	8.16	12.18	1.50
	60	13.5	8.45	12.97	1.59
VII	(25)*	14.8	6.67	9.42	1.09
Fresh Solids	(30)	14.8	7.68	10.46	1.23
Seeding Poor	(35)	16.0	7.02	9.82	1.05
Digestion at 50° C.	(40)	15.7	7.26	10.03	1.10
	(45)	12.1	7.52	10.38	1.48
	(50)	14.7	7.06	9.86	1.15
	(60)	19.4	8.34	11.21	1.01
IV	25	8.2	1.99	1.80	0.46
Activated Sludge	30	6.0	2.07	2.11	0.70
Seeded with Di-	35	6.2	2.57	2.78	0.86
gested Fresh Solids	40	8.0	2.68	2.95	0.70
	45	7.6	2.89	3.17	0.80
	50	7.4	2.95	3.39	0.86
	60	12.2	5.05	6.56	0.95
V	25	3.8	1.47	1.32	0.73
Activated Sludge	30	5.5	1.81	1.76	0.65
Seeded with Di-	35	7.0	1.60	1.45	0.44
gested Activated	40	5.6	1.76	1.85	0.65
Sludge	45	8.5	2.69	2.82	0.65
	50	7.1	2.44	2.77	0.73
	60	8.0	2.93	3.61	0.82
Average for Fresh Solids					1.28
Average for Activated Sludge					0.71

* Indicates temperature at which seeding material was produced.

own data pertaining to this question are summarized in Table IV. There are given the grams of volatile matter destroyed, the grams of methane and carbon dioxide produced, and the weight of gas produced per unit weight of volatile matter destroyed.

In the case of fresh (plain-sedimentation) solids, only two experiments are noted in which a pound of volatile matter, when decomposed, does not yield a pound or more of gas. The yield runs as high as 1.96 pounds per pound of volatile matter destroyed. This seems excessive, but it must be remembered that in the authors' experiments the gas was collected over a

saturated salt solution in an apparatus designed to reduce gas losses to a minimum (see Fair and Moore[3]). No such recovery would be obtained in practice. The average yield for fresh solids, 1.28 pounds of gas per pound of volatile matter destroyed, agrees very well with the data given by Buswell and Boruff[13] (p. 459), and the maximum is well below the theoretical limit they indicate.

For activated sludge, the yield always appears to be less than one pound of gas per pound of organic matter destroyed. This probably indicates a lower percentage content of fats and other rich gas-producing substances than that of fresh solids. This observation also agrees qualitatively with data quoted by Buswell and Boruff[13] (p. 459), which show a mixture of fresh and activated sludges yielding materially less gas than straight fresh solids.

It is hoped that these data may be of some service in clearing up the question of gas yields.

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Effect of Sulphate Salts on H_2S Production in Sludge Digestion*

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Many sewage disposal plants receive wastes containing quantities of sulphates in combination with inorganic and organic materials. This paper treats only with the effect of inorganic sulphates upon sludge digestion. The sulphates may come from various sources, such as infiltration of sea water, hard water supplies containing calcium and magnesium sulphates, pickling liquors from iron works containing iron sulphate, copper sulphate from insecticide manufacturing, sulphuric acid from mine drainage, sulphuric acid industry and paper industry, sulphates and sulphides from dye manufacturing and dye establishments, and numerous other sources. Little is known about the effect of these trade wastes upon digestion. Whether they can be mixed with domestic sewage without detriment, or should be kept out of the disposal plant, whether they can be allowed to enter a plant and in what proportion, what the effect of certain quantities would be upon gas production, odor control, volatile matter reduction, time of digestion and subsequent digestion capacities are all questions of importance to the designing engineer as well as the plant operator.

Materials and Methods.—To determine the effect of sulphate wastes upon the course of digestion, properly seeded fresh solids were mixed with such sulphate salts as might be encountered at treatment plants. The sulphates added were combined with the following: iron, aluminum, copper, zinc, calcium, magnesium, sodium, ammonium and hydrogen. The ripe sludge was obtained from a Plainfield, N. J., separate sludge-digestion tank and the fresh solids collected in the usual manner by hanging pails in the flowing-through compartments of a settling tank. The solids and ash contents of the materials are given below, whereas the different forms of sulphur are shown in the tables.

	Solids	Ash	pH
Ripe Sludge.....	7.23	52.8	7.5
Fresh Solids.....	4.65	20.2	5.9

The materials were mixed on the basis of two parts of volatile matter in the fresh solids to one part in the ripe sludge. The salts used were dissolved in a volume of water equal to the volume of the mixture.

Chemical analyses were made during the course of digestion and included the following determinations: pH, solids, ash, free sulphur, organic sulphur, sulphates, total sulphur and H_2S evolved and dissolved. Gas

* *Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J., Dept. Sewage Research.*

TABLE I

SOLIDS, ASH AND GAS PRODUCED

No.	Added Chemical	Solids Beginning, %	Solids End, %	Solids Reduction, %	Ash Beginning, %	Ash End, %	Vol. Matter Reduction, %	Gas per Gram Vol. Matter Added, Cc.	CO_2 per Gram Vol. Matter Added, Cc.	Combustible Gas per Gram Vol. Matter Added, Cc.	pH Beginning	pH End	Remarks
76	None	5.08	3.54	30.2	33.4	46.3	43.7	830	127	600	7.0	7.4	
77	$FeSO_4$	5.48	4.08	25.5	37.2	49.4	39.9	410	71	300	6.8	7.3	
78	$Al_2(SO_4)_3$	5.54	3.98	28.1	35.7	45.4	39.0	557	126	314	6.8	7.5	
79	$CuSO_4$	5.70	4.90	13.8	38.7	39.7	14.9	4	4	0	6.5	6.4	Incomplete digestion
80	$CaSO_4$	5.60	4.02	28.3	34.0	47.0	42.3	466	88	322	7.0	7.4	
81	Na_2SO_4	5.66	3.88	31.4	35.8	49.7	46.3	456	141	203	7.2	7.3	
82	$MgSO_4$	5.60	3.98	28.8	34.1	45.6	41.3	400	89	282	7.0	7.6	
83	H_2SO_4	5.26	4.46	14.9	33.7	36.1	18.0	102	67	32	6.3	7.1	Incomplete digestion
84	$(NH_4)_2SO_4$	5.14	3.60	29.9	33.5	45.9	43.0	731	149	500	7.0	7.6	
85	$ZnSO_4$	5.60	4.94	11.7	36.1	40.1	17.1	2	2	0	6.9	6.5	Incomplete digestion

measurements were made daily and the gas analyzed for CO_2, O_2, H_2, CH_4 and the remainder called N_2.

The quantities of salts added were on the basis of 1000 p. p. m. in the diluted mixture, corresponding to 150 p. p. m. in sewage with 200 p. p. m. suspended solids.

A special trap containing alkaline cadmium chloride was inserted between the digestion mixture and the gas holders, in order to remove H_2S produced. At the conclusion of the experiment the H_2S was determined by aeration into standard iodine solutions. Carbon dioxide absorbed by the material in the trap was simultaneously determined by reabsorption in a potash bulb. The H_2S in solution in the mixtures at beginning and end was determined by the Salle and Reinke* method. Duplicate analyses were made which gave reasonably close checks, but the method should be considered as a good approximation rather than an accurate determination. Sulphur in organic combination was determined by the differ-

* *California Sewage Works Jour.*, **2**, 208 (1929).

ence between total sulphur and that appearing as free, as sulphides and as sulphates.

Results.—Results of certain analyses of the different mixtures at the beginning and end of the experiment, together with the quantities of gases produced per gram of volatile matter added, are given in Table I. Three of the mixtures were incompletely digested at the end of 40 days. Gas production varied widely, but there was some general relation between the percentage of volatile matter destroyed and the total gas produced per gram

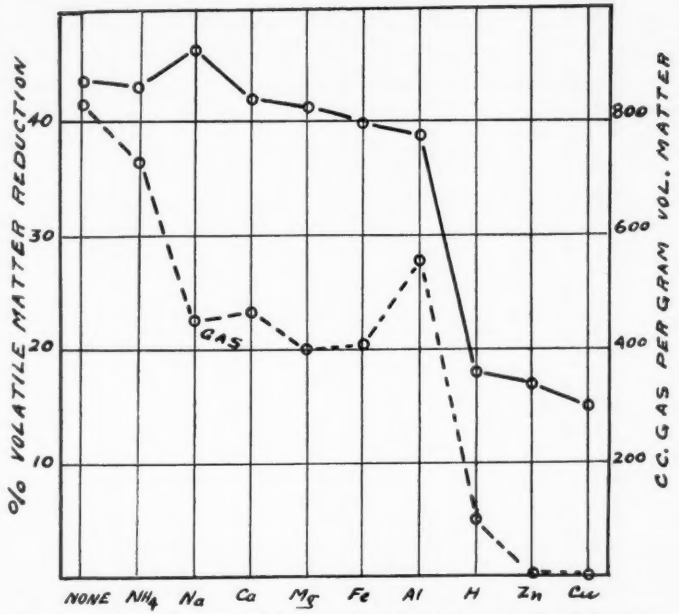

FIG. 1.—Relation Between Volatile Matter Reduction and Total Gas Production from Mixtures Treated with Different Chemicals.

of volatile matter. This is shown in Figure 1. The course of digestion is indicated by the gas production, as illustrated in Figure 2. The quantities of gas produced from the mixtures to which $CuSO_4$ and $ZnSO_4$ were added were extremely small, although some volatile matter reduction took place. Volatile matter reduction in the mixture receiving H_2SO_4 was about the same as in the mixture to which $ZnSO_4$ was added, but gas production was somewhat greater. Most of this gas, however, was CO_2. It is of interest that volatile matter reduction in a number of cases was nearly the same in the sulphate mixtures as in the control mixture, but gas production was considerably less than in the control mixture. All sulphates, therefore,

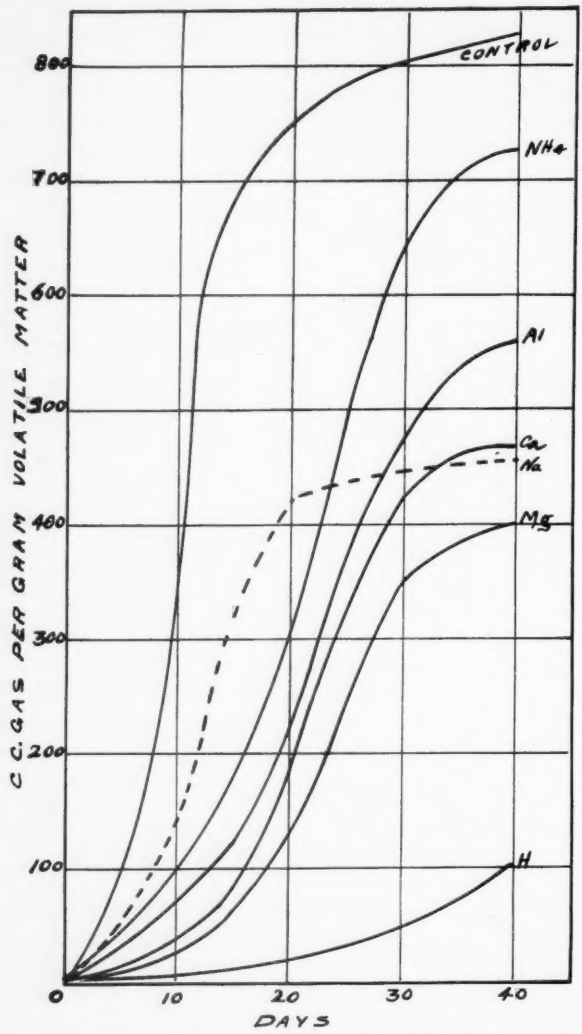

FIG. 2.—Accumulative Gas Production from Mixtures to Which Different Chemicals Were Added.

seemed to have a retarding effect upon the gas production or gas-producing organisms. In general the percentage of ash increase follows the volatile matter reduction.

The different forms of sulphur present at the beginning and end of the experiment, all calculated as sulphur, are given in Table II, while the total sulphur, sulphates added and H_2S production are given in Table III. It will be noticed that in all cases the amounts of free sulphur increased during digestion, whereas the sulphate sulphur was reduced from 39 to 71 per cent in the different mixtures. The organic combined sulphur fluctuated. There was a general relation between total H_2S production and sulphates reduced, while the relation between total H_2S production and the quantities of sulphates added or present in the mixtures was more irregular.

TABLE II

DIFFERENT FORMS OF SULPHUR PRESENT AT BEGINNING AND END
(Calculated as S)

		Free S		Sulphate—S			Organic Combined—S		
No.	Salt Added	Begin., Mgr.	End, Mgr.	Begin., Mgr.	End, Mgr.	Red., %	Begin., Mgr.	End, Mgr.	+ or −, %
76	None	23	104	115	68	41	380	266	−30
77	Fe	32	393	661	192	71	263	263	0
78	Al	29	137	447	180	60	408	303	−26
79	Cu	21	25	610	374	39	318	434	+27
80	Ca	27	61	704	135	81	425	360	−15
81	Na	34	31	247	122	51	351	387	+ 9
82	Mg	60	88	555	241	56	321	238	−26
83	H	54	129	540	216	60	342	333	− 3
84	NH_4	35	62	539	199	63	232	267	+13
85	Zn	21	88	535	173	68	349	654	+47

+ is increase, − is decrease.

The greatest percentage reduction of sulphates occurred in the mixture receiving calcium sulphate, but total H_2S production per gram of sulphate reduced was nearly the lowest from this salt. The relation between total H_2S production per gram of sulphur present as sulphate, added and reduced is clearly shown in Figure 3. These curves represent total H_2S and therefore include the H_2S which was dissolved in the liquid. From an odor-production standpoint it is perhaps of greatest interest to show the relation between H_2S evolved in the gas per gram of sulphur as sulphate present, added and reduced. This relation is illustrated in Figure 4. The greatest quantities of H_2S evolved came from the mixture receiving ammonium sulphate, while the smallest quantities were produced from the sulphate in the form of $FeSO_4$. Although H_2S is produced from $FeSO_4$, as shown in the tables and Figure 4, it remains in solution or is precipitated.

Total gas production per gram of volatile matter destroyed, in relation to the total hydrogen sulphide produced per gram of sulphur present and per

TABLE III

TOTAL SULPHUR, SULPHATES ADDED AND H_2S PRODUCTION (CALCULATED AS S)

No.	Salt Added, Mgr.	$-SO_4$ Added, Mgr.	Total S Present, Mgr.	Total SO_4 Present, Mgr.	SO_4 Reduced, Mgr.	H_2S Produced Dissolved, Mgr.	H_2S Produced In Gas, Mgr.	H_2S Increase, Mgr.	Total H_2S Produced per Gram Sulphates			H_2S Evolved per Gram Sulphates	
									Present, Mgr.	Added, Mgr.	Reduced, Mgr.	Present, Mgr.	Added, Mgr.	Reduced, Mgr.
76	None	0	644	115	47	−27	13	−14	0	0	0	20	0	28
77	Fe	546	1070	661	469	317	5	322	487	590	685	7	9	10
78	Al	332	972	447	260	18	199	217	485	654	845	445	600	765
79	Cu	495	1056	610	236	55	102	157	258	318	865	167	206	432
80	Ca	689	1267	704	569	−26	203	177	252	257	311	286	295	357
81	Na	132	876	247	125	91	40	131	530	1000	1050	162	303	320
82	Mg	440	1090	555	314	−27	313	286	516	626	910	565	712	998
83	H	425	930	540	324	60	68	128	238	301	394	126	160	209
84	NH_4	424	913	539	338	62	418	480	890	1130	1415	778	998	1240
85	Zn	420	1036	535	362	81	7	88	164	209	242	13	16	19

− is less.

gram of sulphur added, is compared in Table IV. There does not seem to be a definite relation between total gas production and total H_2S production. Calculations and plotting of results show also that there is no definite relation between the quantities of gas produced and the amounts of H_2S evolved, either as sulphur present, added or destroyed. With the exception of $CaSO_4$, there was a fairly close relation between the quantities of volatile matter destroyed and the total H_2S production per unit quantity of sulphates added.

Discussion

Attempts to correlate the milligram equivalents of cation present with hydrogen sulphide production or evolution failed. It should be remembered that in every case both the cation and anion may affect digestion. If both depress or both stimulate digestion, the results are relatively easy to determine, but when the effect of the two ions is in opposite directions, it is wellnigh impossible to ascribe certain results to definite causes. In this series of experiments the mono-valent cations, sodium and ammonium follow the control closely, next in order come the divalent alkaline earths, calcium and magnesium, followed by the tri-valent iron and aluminum. From then on the percentage of volatile matter reduction decreases sharply to the acid H_2SO_4

and poisonous $CuSO_4$ and $ZnSO_4$. In general, the retarding effect of the salts increased with a decrease in the alkaline character of the salt added.

The formation of free sulphur, observed on different occasions, is of in-

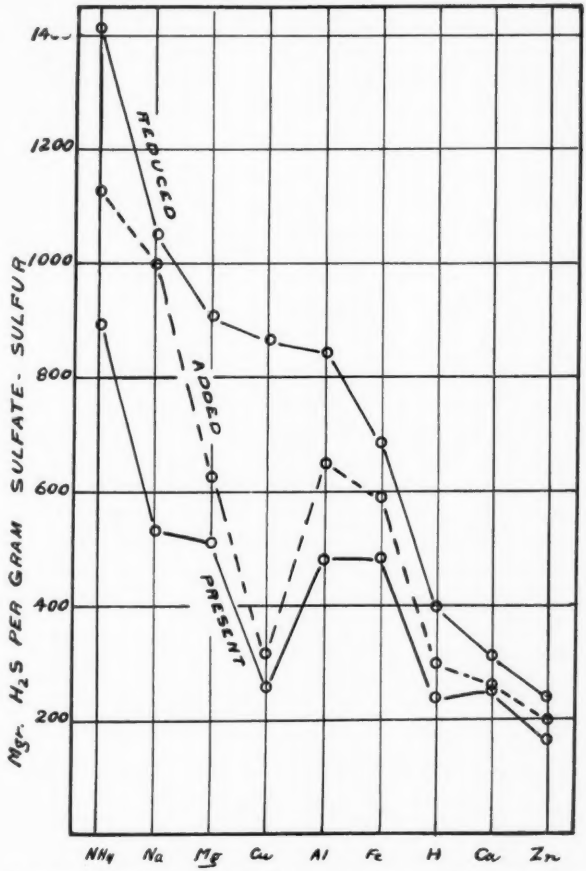

FIG. 3.—Total Hydrogen Sulphide Production per Gram Sulphur as Sulphate Present, Added and Reduced.

terest in connection with the iron salt added. A considerable portion of the sulphates were apparently changed to free sulphur. The walls of the bottle had a yellow coating where the free sulphur was deposited. Con-

siderable quantities of H_2S were produced, but not evolved, and subsequently precipitated. In addition, probably during these processes, sulphur was set free, mostly remaining in suspension. Free sulphur production has been observed previously, also with addition of H_2SO_4 and again in these cases. The fact that free sulphur production occurred in all cases,

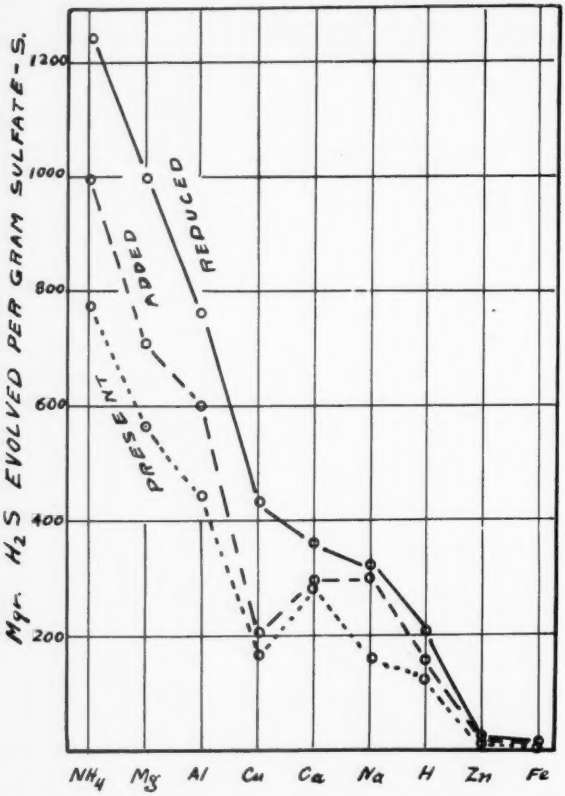

FIG. 4.—Quantities of Hydrogen Sulphide Evolved in the Gas per Gram Sulphur as Sulphate Present, Added and Reduced.

except with the sodium salt, and also in the mixture without any sulphate addition, seems to indicate that the production of free sulphur during digestion is a normal result of the changes taking place in decomposition of mixed solids.

The effects of the different salts upon gas production is indicated by a

reduction in the total gas yield and by the decrease in the rate of gas production. The mixture receiving ammonium sulphate produced more gas than any other mixture to which sulphates were added, but gas production was delayed so that the peak of gas production was not reached until 13 days later, as compared with the control mixture. This delay or lag period is typical of all mixtures. The time required for digestion is accordingly materially increased. In these instances total gas production and the rate of gas production can be taken as a qualitative measure of digestion and not as a quantitative measure, because the relation between gas production and volatile matter reduction is not constant. If these results are typical of the effects of certain wastes received at treatment plants in addition to the domestic sewage, they indicate the reasons for the differ-

TABLE IV

GAS PRODUCTION AND ITS COMPOSITION

No.	Salt Added	Gas per Gram Volatile Matter Destroyed: Total Gas, Cc.	Gas per Gram Volatile Matter Destroyed: Combustible, %	CO_2, %	Total H_2S Produced per Gm. Sulphur Present, Mgr.	Total H_2S Produced per Gr. Sulphate Added, Mgr.
76	None	1250	72.5	15.4	0	0
84	NH_4	933	69.2	19.9	525	1130
78	Al	895	56.5	24.4	224	655
80	Ca	667	69.1	18.7	140	257
81	Na	605	44.6	30.8	150	1000
82	Mg	587	70.6	22.3	262	650
77	Fe	475	73.1	17.1	300	588
83	H	358	30.0	68.0	138	300
79	Cu	5	0.0	100.0	148	317
85	Zn	6	0.0	100.0	85	209

ences in gas production when gas production is calculated either per capita contributing or per pound of volatile solids received.

No definite or direct relation was found to exist between total gas production and H_2S evolved, and although CO_2 evolution varied considerably among the different mixtures, there was no relation between the production of these two gases, either on the basis of sulphates added, present or destroyed. Of the alkaline salts, sodium appeared to stimulate CO_2 production. It appears, therefore, that in general the only index of total H_2S production found, was the reduction of volatile matter, irrespective of the type of sulphates added. If the sulphates are combined with a bacterial poison like Cu or Zn, digestion activities are retarded and H_2S production is less. This is illustrated in Figure 5, where the percentage of volatile matter reduction is plotted against the total H_2S produced per gram of sulphates added. It should be kept in mind, however, that not all the H_2S

produced is evolved in the gas, but a part remains in solution in the sludge liquid. When this liquid is sprayed into the air an additional portion of the H_2S may be released.

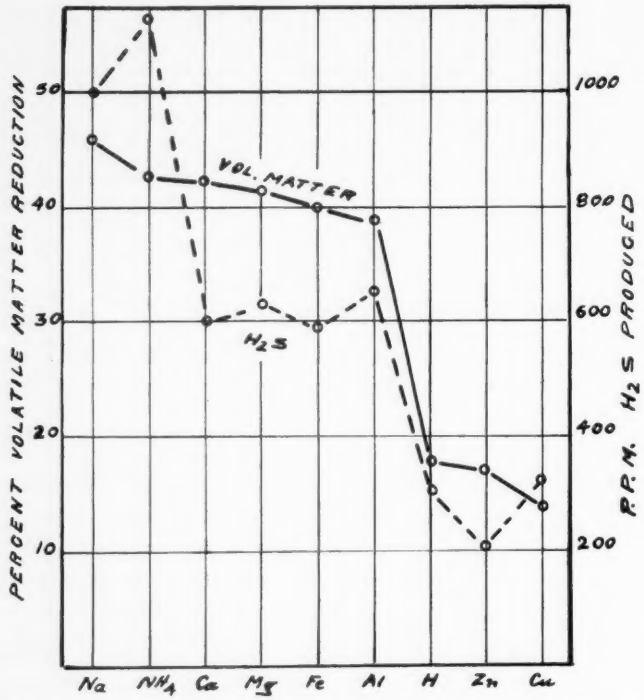

FIG. 5.—Relation Between Volatile Matter Reduction and Total Hydrogen Sulphide Produced per Gram Sulphur Added as Sulphates.

Summary

To mixtures of fresh solids and ripe sludge sulphate ions combined with various cations were added to the amount of 1000 p. p. m. Volatile matter reduction, gas production and the formation of free sulphur and hydrogen sulphide were determined. There was some general relation between the percentage of volatile matter destroyed and the total gas produced per gram of volatile matter added. Gas production was less in all cases where sulphates were added, as compared with the control. There was a general relation between total H_2S production and the quantities of sulphates destroyed, while the relation between H_2S production and the quantities of sulphates added or present was more irregular. There was no definite re-

lation between total gas production and total H_2S production. There was a fairly close relation between the quantities of volatile matter destroyed and H_2S production. Attention is drawn to the formation of free sulphur, which appears to indicate that this is a normal result occurring during digestion. The different sulphates exerted a retarding effect upon total gas production, the rate of gas production and volatile matter destruction, and the time required for digestion was increased.

Enzymes and Sludge Digestion*

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Negative results from experiments are not as interesting as positive, but the recording of carefully controlled experiments producing negative results is often of decided help to other investigators, as well as to the practical operator. A few years ago experiments were reported from our laboratory[1,2,3] on the action of enzymes upon sewage solids. In view of the fact that enzymes did not appear to stimulate destruction of volatile matter, or gas production, other results obtained later in the laboratory and on a plant scale were not published. During the last year several inquiries have reached us indicating that some investigators and plant operators are of the opinion that there are considerable possibilities in this direction. In order to indicate the lines of our work and give whatever aid we can to those interested, the additional results are briefly presented. It is quite possible that further inquiry may lead to decided advantages, although the work done thus far does not appear very promising. Chamberlin[1] found that the effect of enzymes on properly seeded fresh solids was negligible, with the exception of lipase. He surmised that it would be very likely that the enzymes present would be more active if optimum environmental conditions could be maintained, although this would probably be uneconomical.

The different enzymes act upon different constituents of the sewage solids. Those enzymes mostly worked with thus far are: pepsin, trypsin and lipase. Pepsin is the enzyme that hydrolyses proteins to proteoses and peptones. To do this it requires an acid reaction. Trypsin is the catalyst used for converting proteins into amino acids. The greatest activity of this enzyme takes place in an alkaline environment. Lipase changes fats to fatty acids and its activities are greatest in a rather acid medium. The optimum temperature for pepsin and trypsin is around blood temperature, while lipase prefers the higher reaches of thermophilic digestion. It would appear therefore that to make conditions right for the individual enzymes the sludge would have to be digested in stages at different temperatures and changing from acid to alkaline conditions or *vice versa*. If such changes were not made the effects of adding enzymes would probably be very little.

Experiments

The experiments conducted fall into three more or less independent parts. Studies were made on the effect of several enzymes upon the digestion of (1) fresh solids, (2) fine screenings and (3) activated sludge.

* *Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J., Dept. Sewage Research.*

The work on fresh solids was done in the laboratory by adding one gram of enzyme per liter fresh sludge and incubating the mixtures at 28° C. for 35 days. To other portions of fresh solids similar quantities of enzymes were added, the material adjusted to different pH values and incubated for 48 hours at their optimum temperatures before mixing with ripe sludge. The optimum pH value for pepsin (pH 2.5) is so low that practically no digestion will take place. Experiments conducted previously, where the pH values were adjusted at 0.5 increments between pH 1.0 and 13.0, had shown this to be the case. For this reason the fresh solids with pepsin additions were adjusted to pH 5.8.

The materials used were analyzed:

	Solids, %	Ash, %	pH
Fresh Solids	5.56	23.4	5.8
Ripe Sludge	7.85	50.3	7.6
Mixture	7.18	39.8	6.9

All experiments were repeated. A condensed summary of the average results obtained are given in Table I for the mixtures incubated with and without optimum conditions. Gas production from the mixtures receiving enzymes were larger than from the control mixtures when no changes were made in temperature or pH values. The trypsin addition produced most gas; however, the digestion time was not reduced. This can best be shown by the daily gas production curves shown in Figure 1. Only the gas production from the control and trypsin mixtures are shown; the others were between the values plotted.

TABLE I

GAS PRODUCTION AND VOLATILE MATTER REDUCTION AFTER 35 DAYS

	Without Optimum Conditions					With Optimum Conditions				
Addns.	Gas/Gr. Vol. Mat., Cc.	Gas/Gr. Vol. Mat. Destroyed, Cc.	Vol. Mat., Red., %	pH	Temp., ° C.	Gas/Gr. Vol. Mat. Cc.	Gas/Gr. Vol. Mat. Destroyed, Cc.	Vol. Mat. Red., %	pH	Temp. ° C.
None	728	879	38.3	7.4	28	812	911	41.0	7.4	28
Trypsin	830	1076	35.5	7.6	28	745	715	48.0	9.8	55
Pepsin	818	1034	36.4	7.2	28	840	902	42.8	5.8	38
Lipase	768	955	37.0	7.2	28	926	1202	35.4	5.4	38

In the case of optimum temperature and reaction, the mixture to which lipase was added produced more gas than any other, but here again the time required for completion of digestion was practically the same as for the control mixture. A portion of the additional amount of gas came probably from the enzymes themselves, but the quantity of enzyme added amounted only to a few per cent of the total volatile matter present. It appears, therefore, that although the digestion time was the same, somewhat more gas was produced. This is of interest in connection with the percentages of volatile matter reduction, which as a rule were lower for the

mixtures receiving enzymes than for the control mixtures. Comparing the figures for gas production per gram of volatile matter destroyed, the mixtures without optimum conditions to which enzymes were added produced more gas per gram of volatile matter destroyed than the control, but with optimum conditions only lipase produced more gas per gram of vola-

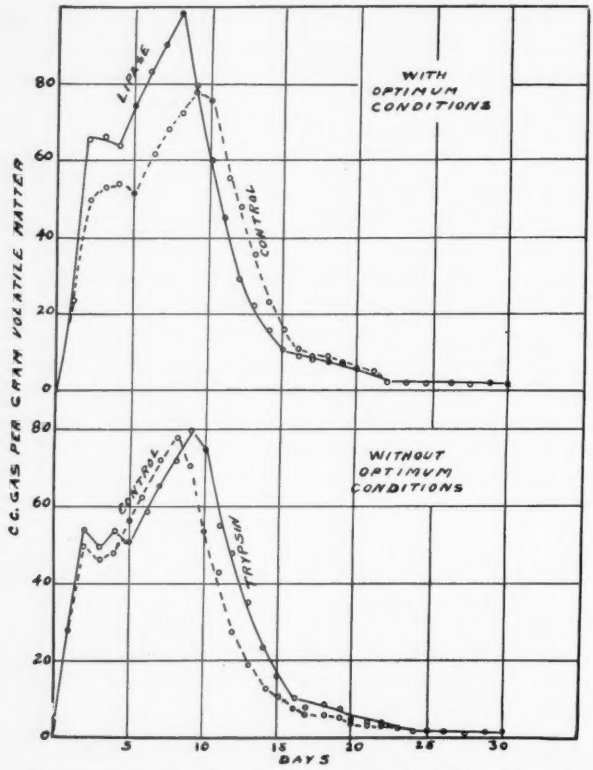

FIG. 1.—Daily Gas Production from Fresh Solids with and Without Optimum Conditions. Results for Other Enzymes Between Those Plotted.

tile matter decomposed. The mixture receiving trypsin produced more gas without optimum conditions than any other mixture, while the same enzyme additions with optimum conditions produced the least. It would appear that in the first case gasification was stimulated, while in the latter liquefaction was greater. Pepsin additions produced somewhat similar results, whereas lipase additions produced the reverse. It was of interest

that the duplicated experimental results were so close that only a few per cent deviation occurred.

Screenings

Experiments with additions of enzymes to decomposing screenings were made in the laboratory and also on a semi-plant scale in Milwaukee, Wisconsin. It may be of more interest to record the semi-plant scale experiments than the laboratory work, especially since the laboratory work gave similar results. The plant experiments were made under the general direction of Mr. Robert Cramer, at that time chief engineer, while the work was conducted by Mr. H. M. Heisig, research chemist at the Milwaukee sewage treatment plant.

In the course of large scale digestion experiments, for which a series of tanks had been built, it was suggested that quantities of enzymes be added to stimulate digestion. Although laboratory experiments previously made had shown very little, if any, effect, the enzymes, trypsin and pepsin, were added to obtain more information. The suggestion was also acceptable, because it would demonstrate whether or not general conclusions derived from laboratory experiments would hold for plant scale work.

Four digestion units described by Townsend[4] were used, each with a capacity of 116 cubic feet. Tank 1 was kept at 82° F.; Tank 2 received the enzyme trypsin and was kept at 104° F.; to Tank 3 pepsin was added, temperature was kept at 104° F. and the reaction was maintained at pH 3.0; while Tank 4 was to be held at 104° F., without any addition or reaction control. One ounce of the enzyme trypsin was added to the tank daily for a period of five months, thereafter the quantities of enzyme were gradually increased until near the end of the experiment not less than 4 pounds of enzyme were added daily. The enzyme was injected into the sludge when this was daily circulated by pumps to obtain good seeding and mixing. (Incidentally it may be noted here that this partial circulation of sludge did not seem to affect materially either the rate of digestion or the rate of gas production from the screenings.) The sludge in all tanks was circulated. The enzyme pepsin was also applied at a rate of one ounce a day. As pepsin is most effective in a medium of about pH 2.5 it was necessary to adjust the pH of the tank contents with sulphuric acid. Aside from the fact that laboratory experiments had shown that no action took place at this low pH, it would be practically impossible to maintain it. In addition the danger of wrecking the tanks and equipment with the large quantities of acid was not to be forgotten. An attempt was made to reduce the pH values to 3.0, but after 6 weeks of operation, with a lowest pH of 4.2 reached, the experiment was abandoned as impractical. Gas production had stopped completely and at the end the mass in the tank had a grayish color, and an intensely penetrating, sour pigpen odor.

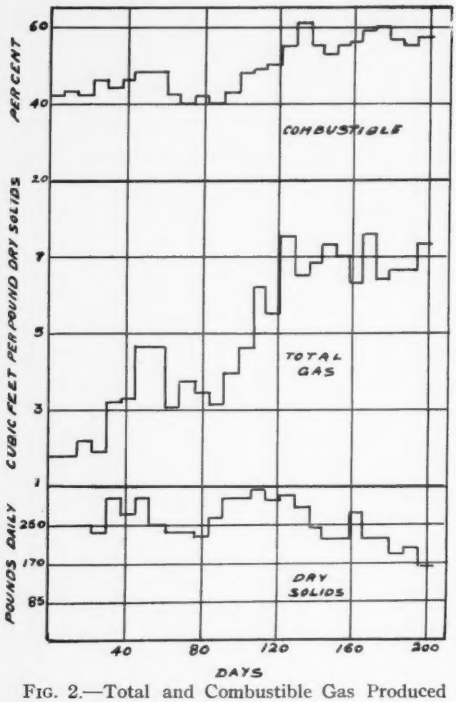

FIG. 2.—Total and Combustible Gas Produced from Screenings to Which Trypsin Was Added; Mixtures Kept at 104° F.

The addition of trypsin was continued for 203 days. The amounts of dry solids added daily, gas production per pound of dry solids and the percentage of combustible gases are graphically shown by weekly averages in Figure 2. Before trypsin additions were made the tank had been operated for about two months. Gas production increased gradually, but it required about 4 months, after the enzyme was added, before gas production reached its highest level. A comparison of the results obtained with enzyme additions at a temperature of 104° F. with screenings receiving no addition and kept at the same temperature, and the third tank, with straight digestion at 82° F., is given in the condensed results reported in Table II. The smallest quantities of dry solids were added daily to the tank with trypsin addition.

Gas production per pound of dry solids appeared to be higher with en-

TABLE II

CONDENSED OPERATION RESULTS

Enzyme Added	Trypsin	Nothing	Nothing
Days Operation	203	61	286
Total Dry Solids Added, Lb.	50,148	16,188	81,885
Total Gas, Cu. Ft.	208,000	35,390	430,400
Average Daily Dry Solids Added, Lb.	247	265	289
Gas per Lb. Dry Solids, Cu. Ft.	4.15	2.19	5.25
Average Temperature	104	104	82
Average pH	8.3	8.2	8.0
Average CO_2, %	39.8	41.7	38.8
Average Combustible, %	53.1	41.4	52.1
Average CO, %	2.0	1.2	1.8
Hydrogen, %	0.0–3.4	..	0.0–5.7

zyme additions than without, but was lower than from the screenings kept at 82° F. The quantities of CO_2 produced from screenings are always higher than from fresh solids and consequently the percentages of combustible gases are lower. The apparently greater gas production from the material to which enzymes were added is due to the longer duration of the experiment. If the results obtained from the two tanks over a more equal length of time, collected during the same time and with charges of screenings made simultaneously, are compared, it appears that the gas production from the enzyme treated material was practically the same as from the untreated material. A condensed summary of these results is shown in Table III. The data in Tables II and III seem to offer convincing proof that the addition of trypsin was of no practical importance. Incidentally, the figures show that more solids could be handled and more gas was produced per pound of dry solids when the materials were digested at 82° F. than when kept at 104° F. The time of operation (about 7 months)

TABLE III

COMPARISON OF RESULTS OBTAINED DURING SAME TIME

Enzyme	Trypsin	Nothing	Nothing
Days Operation	60	61	61
Total Dry Solids, Lb.	17,647	16,188	16,016
Total Gas, Cu. Ft.	39,500	35,390	82,800
Average Daily Dry Solids, Lb.	294	265	262
Gas per Lb. Dry Solids, Cu. Ft.	2.24	2.19	5.17
Average Temperature	104	104	82
Average pH	8.1	8.2	8.0
Average CO_2, %	40.2	41.7	39.7
Average Combustible, %	45.4	41.4	41.3

would seem sufficiently long to draw this definite conclusion, especially if it is considered that gas production from the screenings with enzyme additions had been on a fairly even level for nearly 3 months. Moreover, the changes in composition of the gas produced were very similar. This is perhaps best illustrated by the maximum and minimum percentages of the different components:

	% CO_2			% CO			% Combustible		
	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Av.
Trypsin (104° F.)	44.4	31.6	39.8	3.0	0.1	2.0	60.9	40.0	53.1
Nothing (82° F.)	44.6	30.1	38.8	4.3	0.1	1.8	62.3	39.0	52.1

The behavior of the material in the tanks was similar in all three cases. The mass of material had a tendency to rise, forming a heavy blanket. Sludge circulation, pumping the liquid on top of the blanket helped, but was insufficient to keep the blanket down.

Although it was demonstrated that the screenings could be digested, the

attendant mechanical difficulties made the process impractical and the experiments were abandoned. With different mechanical features the process may be possible, but additions of trypsin did not alleviate the difficulties. Additions of pepsin greatly complicate the mechanical equipment and it is very doubtful, with the present state of our knowledge (and this conclusion is based mainly upon laboratory experiments) that pepsin additions would aid the digestion processes materially. The fact that the continued large scale experiments showed identical results with the laboratory experiments are worthy of notice.

Activated Sludge

The experiments with additions of enzymes to activated sludge were conducted on a small scale. Tanks of about 30 gallons capacity were used. The results obtained over a period of three months were so similar to those reported above for fresh solids and screenings that they represent a repetition of the findings. There was no practical difference between the materials receiving enzymes and the sludge that did not have any additions. In regard to length of digestion time, gas production and material handled, the small differences observed were well within the limits of experimental errors.

Discussion

Sanitary chemists and engineers are forever on the alert for new and better methods of sewage treatment. Since enzyme action takes such an important part in the destruction and stabilization of sewage solids it would seem logical that additions of strong cultures of enzymes to sewage solids should exert a decided influence. The experiments conducted by us thus far do not show that the digestion time is decreased even with addition of comparatively large quantities of enzymes. In general somewhat more gas was produced, while in some cases volatile matter reduction was less. With lipase additions under optimum conditions somewhat more gas was produced per gram of volatile matter destroyed, but with trypsin the reverse occurred. Trypsin seemed to stimulate liquefaction. That no greater differences were obtained may be due either to (1) faulty experimentation, or (2) to the fact that the complex bacterial groups produce sufficient enzymes once the process is established, and any addition is superfluous. By faulty experimentation is meant that the optimum reaction could not be maintained, consequently a re-study still remains in the realm of practical operation. Experimentation that disregards entirely practical application is often necessary to establish a principle, but the fact that enzymes are active, occur, increase and decrease during digestion has been demonstrated,[1] so that the questions to be answered are: does addition of enzymes help the digestion processes; is the rate of and total gas production

increased; how do additions affect liquefaction, drainability, odor, etc.? The questions regarding gasification and liquefaction have been answered. Drainability is affected in that certain enzymes (like lipase) cause the material to swell and hold the water for longer periods, whereas trypsin causes the material to give up its water more rapidly. When the reaction is adjusted to make the materials acid, odors are considerably intensified, but without adjustment little or no differences could be noticed. It would appear, therefore, that the type of experimentation was more or less correct to determine the controlling factors and the results must be taken at their face value. With our present knowledge it would seem that the bacterial groups produce sufficient different enzymes during the digestion processes and any further addition is unnecessary. It may be argued that if the different enzymes were added in succession, one after the other, better results would be obtained. A study of the occurrence, increase and decline of the enzymes during the decomposition processes does not substantiate such an argument, because nearly all enzymes reached their maximum quantities (values) when gasification was at its peak. Moreover, addition of a group of five different enzymes did not exert any material difference. In general, it appears that considerably more information must be obtained before the addition of enzymes to decomposing fresh solids, screenings or activated sludge is interesting from a practical standpoint. The difficulty of changes in temperature and reaction seem to form especial obstacles.

Summary

Digestion experiments were conducted in the laboratory and on a semi-plant scale with fresh solids, fine screenings and activated sludge to which different enzymes were added. Some of the experiments were conducted under as nearly as practicable optimum temperature and reaction conditions for the greatest activities of the enzymes added. The results show very little practical difference, if any, in regard to digestion time, gas production, material handled, drainability and odors, between the materials to which enzymes were added and those digested alongside without enzymes.

References

[1] Chamberlin, N. J. Agr. Expt. Sta., *Bull.* 500 (1930).
[2] Chamberlin, Proc. N. J. Sewage Works Assoc. (1930).
[3] Rudolfs, *J. Boston Soc. Civ. Eng.*, 37–52 (1929).
[4] Townsend, *Proc. Am. Soc. Mun. Imp.*, 173–97 (1928).

The Removal of Suspended Solids and Production of Gas by the Imhoff Tanks of Decatur, Illinois*

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The Imhoff tanks at Decatur were constructed as part of the original plant in 1923. They consist of six units, each 27 ft. 10 in. wide and 96 ft. long. The liquid depth is 27 ft. below the overflow weirs and the free board is 24 inches. The gas vents, which were originally open to the air, were reconstructed in 1926 to collect the digestion gases, by building a submerged arched roof in each vent which terminated into 18-in. tile between each walk way. Over these tile were placed galvanized metal bells for collecting the gases. The collecting bells were originally connected by insulated 1-in. pipes but these small pipes froze badly in sub-zero weather and have been replaced by 2-in. galvanized pipes. The 2-in. pipes frost up in sub-zero weather and insulate themselves with cellular ice crystals, and at 17° below zero have not frozen due to the insulating properties of the frost lining.

The six Imhoff tanks provide the following capacities.

	Cu. Ft.
Settling	63,700
Sludge	181,000
Neutral Zone and Scum	83,000

This settling volume provides a displacement period of 1.44 hours at 8 m. g. d., 1.15 hours at 10 m. g. d., 0.96 hour at 12 m. g. d. and 0.68 hour at 17 m. g. d. the hydraulic capacity of the plant. The normal variation of sewage flow is between 8 and 12 m. g. d., thus averaging slightly more than one hour's displacement period. The sludge digestion capacity is slightly over 3 cu. ft. per capita of the human population.

The sludge drying bed capacity is 56,500 square feet or slightly under 1 sq. ft. per capita.

Excess activated sludge from the pre-aeration plant and the humus sludge from the secondary settling tanks are pumped into the influent sewage ahead of the Imhoff tanks.

The data presented in this paper cover the four years 1928, 1929, 1930 and 1931. In Table I are the average daily data for each year.

Sewage Flow.—The sewage flow treated in the Imhoff tanks is measured by a recording venturi meter which is calibrated by a manometer tube. The sewage flow in 1929 represents an abnormally wet year, while

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that in 1931 an abnormally dry year and a depressed industrial condition. The average daily sewage flows through the tanks during 1929 and 1931 were 11.55 and 9.00 m. g. d., respectively. The maximum daily flows at times of storm may run as high as 15 m. g. d. and the minimum daily flow when the starch industry is shut down will vary between 5 and 6 m. g. d.

TABLE I

SOLIDS REMOVED AND GAS PRODUCED IN THE IMHOFF TANKS AT DECATUR, ILLINOIS

	1928	1929	1930	1931
Sewage Flow, M. G. D. per 24 Hours...	10.35	11.55	10.45	9.00
Suspended Matter:				
Crude Sewage, P. P. M.....	202	183	200	224
Imhoff Effluent, P. P. M..... ..	88	98	87	90
Per Cent Removal by Tanks.....	56.5	46.3	56.5	59.8
Pounds Solids to Digestion Chamber per 24 Hours:				
(1) Settled from Crude Sewage.....	9,800	7,600	9,500	10,400
(2) As Excess Activated Sludge and Humus Sludge.....	neg.	1,100	2,900	3,600
Total (1) and (2).....	9,800	8,700	12,400	14,000
Cubic Feet of Gas Collected per 24 Hours	50,000	49,300	46,800	46,600
Average Temperature of Digestion, ° F..	77	74	74	73.5
Cubic Feet of Gas per Lb. of Dry Sludge Added:				
On the Basis of Sewage Solids Alone..	5.1	6.5	4.95	4.5
On the Basis of Sewage, Activated and Humus Sludge.....	5.1	5.7	3.8	3.3

Suspended Matter.—The average suspended matter in the crude sewage varies between 100 and 300 p. p. m., but during normal years the average is very close to 200 p. p. m. The suspended matter in the effluent is usually between 80 and 90 p. p. m. except during high storm water flows when the detention period is reduced. Between 50 to 60 per cent of the influent suspended matter is settled out at the normal detention period of 55 to 70 minutes. During the hot summer months, with a dry weather sewage flow and a higher suspended matter content removals of 60 per cent or better are common, while during the spring months, with increased flow and lower suspended matter content, the removals have been as low as 40 per cent.

Solids Added to the Digestion Chamber.—The solids added to the digestion chamber consist of fresh sewage solids and excess activated and humus sludge. The fresh solids are calculated from the difference in suspended matter in the crude sewage and tank effluent. This figure is as accurate as the sampling error which is probably high in the crude sewage and negligible in the effluent. The determination is made each morning on a composite of hourly samples taken during the preceding 24 hours

from 7 A.M. to 7 A.M. The compositing sample is kept in a cooler at about 10° to 12° C.

The average daily removal of suspended matter has varied from about 6000 to 15,000 pounds per 24 hours, with a daily average during 1928 to 1931 of approximately 10,000 pounds per day. However, the monthly averages vary greatly from this figure; about 50 per cent being in the 6 to 8 thousand pound zone, 30 per cent being in the 12 to 14 thousand pound zone, thus leaving only 20 per cent of the monthly averages in the 9 to 11 thousand pound zone or average zone.

Until August, 1929, the return of any excess activated sludge to the tanks had been negligible and the secondary settling humus sludge was lagooned on the property. Since August, 1929, the humus sludge has been pumped into the activated-sludge well and circulated through the pre-aeration process with the activated sludge and wasted with the excess activated sludge, when such existed, to the influent sewage, or by manipulating the return sludge pumps the humus is sent directly with some activated sludge to the influent sewage.

The pounds of this sludge thus entering the digestion compartments are calculated from the volume of sludge pumped (recording venturi meter) and from 18 months of analyses of per cent solids in the returned sludge. I do not feel at all satisfied with the accuracy of these figures due to the difficulty in obtaining a representative sample of sludge during pumping. However, the figures show the relative additional amounts of sludge added to the digestion chamber. Some scattering data indicate that this returned sludge will average about 50 per cent secondary humus sludge and 50 per cent activated, although this will vary greatly during different months and methods of operation.

Of the daily load on the digestion chamber during 1930 and 1931 of from 12,000 to 14,000 pounds of dry sludge, about 25 per cent was activated and humus sludge and about 75 per cent fresh sewage sludge.

Gas Production.—Practically all the gas is collected and measured through a Foxboro orifice meter. The volumes are corrected to 60° F. and 29.90 inches of mercury, which is standard industrial gas practice. Before adding the excess plant sludges the gas volume was about 50,000 cu. ft. per day, but during 1930 and 1931, although the added solids increased to 12,000 and 14,000 pounds per day, the daily gas volume dropped 5 to 7 per cent (or to about 47,000 cu. ft. per day).

Temperature.—Variations in gas production above and below the average follow more closely the temperature variations than any other factor. The Decatur sewage is warmed throughout the year by 3 m. g. d. of barometric condenser water which leaves the starch works at about 110° F. Sewage temperatures range from 90° to 105° F. in summer and from 60° to 70° F. in winter. The lowest gas production usually occurs

during February, March and April when the sewage temperatures are low due to melting snow and cold rains. At times of melting snow the gas production has decreased to less than 10,000 cu. ft. per day for short periods. The maximum daily gas production during summer and fall occasionally reaches 80,000 to 90,000 cu. ft. but maximum monthly averages during the four years have been between 60,000 and 80,000 cu. ft. per day.

Sludge Withdrawals.—Gas production is temporarily reduced by withdrawals of large amounts of sludge to the drying beds. Although this procedure is not recommended, most plants find it necessary to draw considerable sludge as soon as the spring drying weather occurs. The data on quantity of digested sludge withdrawn at Decatur is unreliable for a number of reasons: (1) during the winter months it has been necessary to draw sludge to a lagoon and although we estimated the quantity withdrawn it was a very rough estimate, (2) dry sludge has been removed from the drying beds by the country clubs and others and no record has been kept of sludge so removed, (3) because of the ideal digestion temperature conditions a well-digested sludge was always produced and we have neglected the routine analyses of digested sludge for a more thorough study of the starch waste-sewage mixture and the purification of the sewage. It is, therefore, impossible to make a solids balance or to calculate the gas produced per pound of volatile matter destroyed.

Occasional studies of the sludges indicate the following analyses which are given for what they are worth and in no way as routine averages.

Volatile Matter:	
Fresh Sewage Solids	50–60%
Mixed Activated and Humus Solids	50–60%
Digested Sludge	±35%

Gas Produced per Pound of Dry Sludge Added.—In the tabulated data in Table I are found the average cu. ft. of gas produced per pound of dry sludge added, both on the basis of fresh sewage solids and on the combined sewage solids plus estimated activated and humus sludge solids. There has been a very noticeable decrease in the gas produced per pound of sludge added since the addition of the activated and humus sludge solids. This may be due to three causes as follows: (1) lower gas production of the aerobically produced sludge, (2) slower digestion of this aerobically produced sludge and (3) a shorter time for digestion due to greater crowding of the digestion capacity and consequently a larger withdrawal of sludge to the drying beds before the gasification stage has been completed.

pH of Digestion Sludge Liquor.—The pH of the sludge liquor six inches above the sludge blanket is taken in each tank once a week and has remained between 6.6 and 7.0 for the past four years. There has been no

foaming or lime treatment during this four-year period, although the pH has averaged 6.8.

Scum Formation.—Scum formation in the gas collectors has not been a serious item of maintenance. The majority of the gas domes are not taken off and cleaned more than once or twice a year. This spring about 12 of the 108 gas domes have been cleaned monthly. These domes are near the inlet ends of the tanks and the scum formation seems to be aggravated by the very large accumulation of snail shells that have sloughed off the sprinkling filters.

Summary.—The Imhoff tanks have given very satisfactory removal of suspended matter, considering the short detention period, which is necessary to prevent putrefaction of our warm sewage starch-waste mixture.

An average of from 45,000 to 50,000 cu. ft. of gas per day has been produced, with an average temperature of 74° F., and a daily addition of from 10,000 to 14,000 pounds per day of dry solids.

The addition of activated and humus sludge to the digesting solids has materially reduced the gas produced per pound of dry solids added, but has not materially affected the operation of the Imhoff tanks in any other way.

Rapid Moisture Determination of Sewage Sludge

BY HENRY WEINER

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The moisture determination of a sample of sewage sludge usually involves considerable delay before the final data are obtained. The wet sludge is first weighed in a previously tared evaporating dish; a lapse of time follows for drying the sample (in the Baltimore sewage works laboratory the sample is left in the drying oven overnight); the dried sample, after cooling in a desiccator, is finally weighed and its weight recorded. A series of calculations follows to get the desired result after at least six hours of waiting. For precise work this procedure is necessary and recommended. There are times, however, when precision must give way to the exigency of time, and various methods have been tried to decrease the time required to make this test. This saving of time is especially necessary when preparing sludge for dewatering by vacuum filtration.

The electric centrifuge was tried for this purpose with little success. Unless intricate calculations are resorted to,[1] one cannot use this apparatus and get consistent results. There are many variables involved, and graphs drawn from average tests produce results which are too far from the correct figures to be applicable. The test, as conducted in Baltimore, required centrifuging a definite quantity of the sample in a graduated centrifuge tube for three minutes at a set point on the rheostat, which formed part of the equipment of the machine. The machine, however, did not always operate at the same speed due to variations in the voltage. The solids, which were thrown out of suspension, did not lie evenly in the test tube, and it was necessary to approximate their actual volume in the tube. This method was so inaccurate that its use had to be discarded.

While making certain tests with a Büchner funnel, involving the dewatering of sludge by the use of ferric chloride "conditioner" and vacuum filtration, the writer observed that under certain constant conditions the shrinkage of the cake remained the same. If this is true, the liquid filtered from sludges of varying moistures should increase or decrease proportionately, provided the volume of the sample, the amount of conditioner, the time of mixing the ferric chloride with the sludge and the vacuum applied be constant. Extensive tests have shown that this method gives a maximum error rarely greater than $^1/_2\%$, as shown in Table I.

Apparatus and Materials

It is suggested that the following apparatus and materials be used in making the test:

[1] G. C. Whipple, "Microscopy of Drinking Water," 4th Ed., p. 103.

Büchner funnel with at least 200 ml. capacity from the top of the perforations to the top of the funnel (listed as size 2a).

No. 4 Whatman filter paper. If other paper be used, the kind and quality should be constant.

Vacuum source, preferably equipped with a vacuum gauge.

Beakers of 300 ml. capacity.

Stainless steel spatula with a 6-in. blade.

Ferric chloride solution. Dissolve the salt in distilled water so that 20 mls. contain exactly 1 gram anhydrous $FeCl_3$.

TABLE I

MOISTURE OF SLUDGE AS DETERMINED BY THE PROPOSED FILTER METHOD

Sludge Sample No.	Moisture Determination by "Standard Methods," %	Moisture Determination by Proposed Filter Method: Quantity of Filtrate, Cc.	Moisture,* %	Deviation from Actual Moisture, %
1	93.60	152	93.62	+0.02
2	94.09	153	93.69	−0.40
3	94.09	156	93.93	−0.16
4	94.33	158	94.09	−0.24
5	94.86	160	94.26	−0.60
6	94.65	162	94.42	−0.23
7	94.05	163	94.50	+0.45
8	94.58	164	94.57	−0.01
9	94.39	164	94.57	+0.18
10	94.33	164	94.57	+0.24
11	94.72	164	94.57	−0.15
12	94.72	167	94.83	+0.11
13	94.44	168	94.90	+0.46
14	94.79	168	94.90	+0.11
15	94.79	172	95.23	+0.44
16	94.91	174	95.39	+0.48
17	96.84	186	96.37	−0.47
18	96.99	190	96.70	−0.29
19	96.72	193	96.94	+0.22
20	96.95	198	97.36	+0.41
Average	94.97		94.94	+0.0285
			Average error	+0.03%

* As obtained by diagram.

NOTE: Samples 2, 7, 13, 15, 16, 17 and 20 represent "raw" sludge, pH 4.7 to 5.1. All other samples were of sludge in an advanced stage of digestion, pH 6.7 to 7.0.

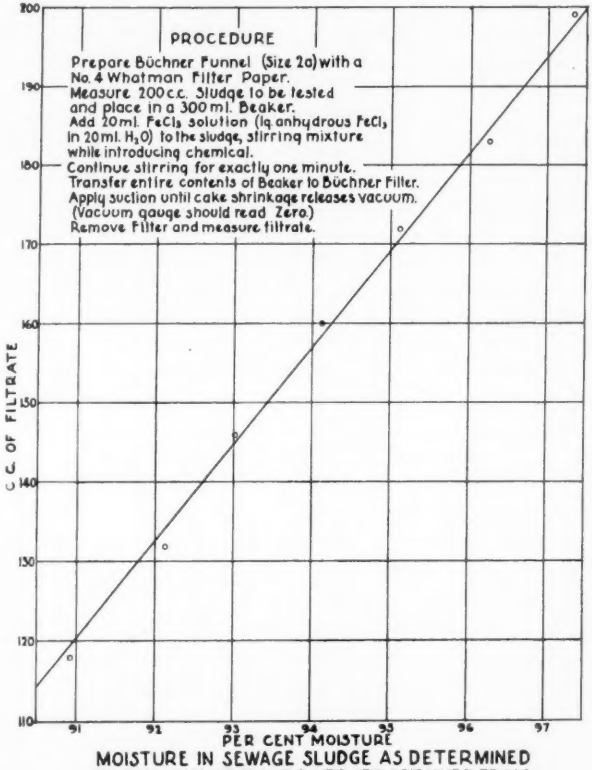
Procedure

Prepare the funnel for sludge filtration by placing a 9-cm. circle of filter paper therein; wet the paper while it is in the funnel; and place it in an aspirator flask. Apply the suction until the water ceases to drop from the funnel stem, empty the flask and replace the damp filter in the neck.

Measure 200 cc. of the sludge to be tested, which has been well mixed

and represents a fair portion of the sample, and place it in a 300-cc. beaker. Add 20 cc. of the ferric chloride solution, stirring the mixture while adding the chemical. Continue to stir the mixture until exactly one minute has elapsed. It was found that by using the blade of a stainless steel spatula for a stirring rod, mixing was far more effective than with a glass rod.

After sufficient mixing, pour the entire contents of the beaker into the



MOISTURE IN SEWAGE SLUDGE AS DETERMINED BY THE QUANTITY OF FILTRATE OBTAINED FROM VACUUM FILTRATION.

filter, scraping out whatever sludge may adhere to the sides of the beaker with the blade of the spatula. Apply suction, and allow it to continue until the shrinkage of the cake causes the entire release of the vacuum with the vacuum gauge registering zero. Then remove the funnel from the bottle and measure the filtrate. By referring to the graph, the moisture of the sludge can be determined. If the sludge is too thick to be con-

ditioned properly by the specified amount of conditioner or if it comes outside the range of the graph for the same reason, it may be diluted with a like volume of distilled water and 200 cc. run through as above. The resulting *solids* determination should be multiplied by 2.

Discussion

The use of this method to determine sludge moisture presents numerous advantages. It makes it possible for the operator of a small plant to ascertain the moisture of liquid sludge without the expensive outlay of apparatus necessary for precise methods. Where sludge is dewatered by vacuum filtration, a knowledge of the solid content of the sludge may produce a saving in the quantity of ferric chloride used, and increase the efficiency of the operation.

The test is so simple that it can be made by many sewage works operators who would not have the training to make the test as outlined in "Standard Methods." One with ordinary intelligence could easily be instructed to make this simple determination. If necessary, a table can be prepared from the graph in order further to simplify the determination.

It should be understood that the sludge used to prepare the diagram is that from the Baltimore sewage works, where separate sludge digestion is used and where the sewage is from a separate sewerage system. Sludge from a combined system of sewers or that from activated-sludge plants may not react in the same manner as Baltimore sludge. For this reason an outline of the method by which the graph was prepared is presented. By following this method the investigator may prepare another graph and apply it to his particular type of material. The peculiar advantage of this method is that uniform results have been obtained when working with the same type of sludge.

A 5-gal. carboy of thick sludge was obtained, and the moisture of a small, representative sample was determined in the usual manner. A series of dilutions was made with this material so that sludges having 91, 92, 93, 94, 95, 96 and 97% moisture were obtained. Careful mixing by pouring the contents of one beaker into another accompanied each step of the procedure. The moisture of each of the diluted mixtures was determined by the standard method. The moisture in the remainder of the diluted sample was determined, in triplicate, by the filter method. In each case the respective quantities of filtrates of the triplicates were the same. After obtaining the actual moisture by "Standard Methods" and the quantity of filtrate by filtering, these results were plotted, using moisture in per cent as abscissa and the quantity of filtrate as ordinates. After a graph has been prepared, it should be checked for a sufficient period of time to establish its accuracy.

The sewage works is under the general supervision of B. L. Crozier, chief

engineer of the Department of Public Works, and George E. Finck, sewerage engineer. Acknowledgments are due to L. L. Hedgepeth, technical advisor of the Pennsylvania Salt Manufacturing Co., with whom the above-mentioned sludge dewatering tests were conducted, to C. E. Keefer, principal assistant engineer, G. K. Armeling, superintendent, and E. C. Cromwell, principal sanitary chemist of the sewage works.

Plant Operation

Erie Sewage Treatment Plant*
Design and Preliminary Results of Operation

By A. B. Cameron

Superintendent, Erie Sewage Treatment Plant, Erie, Pa.

This paper deals mainly with the operation and "tuning up" processes of the Erie, Pa., Sewage Treatment Plant.

The plant was placed in operation October 2, 1931, and has been under the supervision of the designing engineers since that date. Unfortunately, the city was delayed in employing a resident superintendent so that little in the matter of records is available. Likewise the period of organization and "tuning up" has been considerably delayed—in fact, at this writing one might say that the major adjustments have just been completed and we are about ready to start the smoothing out of operating details, the establishment of suitable laboratory routine and the keeping of records. The "tuning up" period is naturally one of troubles and worries, so it follows that a paper dealing almost exclusively with this period will have to deal with these difficulties, what caused them and how they were overcome.

The trend today is toward more mechanical devices and apparently this is a well established movement. In large plants like the Erie Treatment Plant where every modern mechanical device has been utilized, it was to be expected that some mechanical difficulties would be encountered and fortunately these have been the only problems encountered at Erie. The purification processes proper have been exceptionally satisfactory.

General.—The City of Erie is located in the extreme northwestern part of the State of Pennsylvania on Lake Erie. The city is rectangular in shape and has an area of about nineteen square miles. The topography of Erie is nearly flat with a slight slope upward from the Lake on the north to the southern section of the city. The population in the 1930 census was one hundred and sixteen thousand.

Sewerage System.—The city is well sewered and it is estimated that ninety-five per cent of the population is provided with adequate sewers. Some of the sewers are of the combined type and others strictly sanitary. It is estimated that there are two hundred and twenty-five miles of sewers, of which approximately one hundred and fifty-seven miles are of the com-

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bined type. The combined sewers are confined mainly to the older sections of the city. The sewage is collected by three main interceptors which converge at the plant into one sixty-six-inch plant interceptor. One lift station is required which lifts the sewage from a part of the northeastern section of the city.

In addition to the city proper, three small communities have been permitted to connect to the sewerage system. The sewage from these communities is metered and they are charged an apportionate share of all costs of treatment and improvements.

Plant.—Briefly, the plant is of the separate sludge-digestion type, employing only primary treatment. It comprises a control building; an-

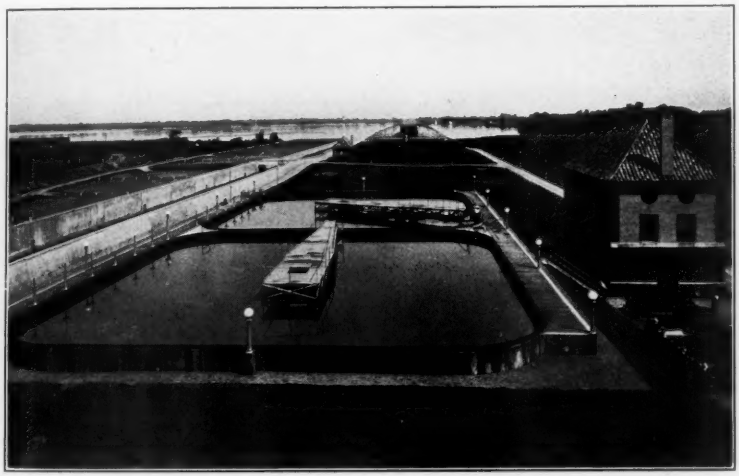

FIG. 1.—Erie Sewage Treatment Works. Clarifiers, Administration Building, Sludge Beds, Digestors and Mill Creek Channel.

other building housing the auxiliary units: Dorr clarifiers; Dorr digestors; and open sludge beds. The control building houses a ten-foot, mechanically cleaned Dorr screen, incinerator, grease-skimming tank, garage, work shop and grit conveying apparatus. The grit chambers consist of two thirty-foot Dorr detritors equipped with grit washing classifiers. A grit storage hopper is provided. Primary sedimentation is effected by means of two ninety-foot square by fourteen-foot side wall depth, traction type Dorr clarifiers. The clarifiers will afford a one-hour detention period at a forty m. g. d. rate of sewage flow; at present, the detention period is slightly over one and one-half hours. Immediately adjacent to these clarifiers is a three-

story control building in which are located the primary sludge pumps, central electric control panel, boiler, complete chemical laboratory, office, lavatory, dry-feed machines and ample storage space. The plant effluent is discharged through an eleven hundred-foot outfall sewer into Lake Erie.

The sludge is digested in three eighty-five-foot diameter by twenty-two-foot side wall depth Dorr digestors which are equipped with sludge-stirring and scum-breaking devices. Near these digestors and housed in a suitable building are the gas meters, one for each digestor, flame trap, gas pressure relief valve, boilers for sludge heating, lime feed machines and sludge recirculating pumps. Twelve open sludge beds are provided which have a total area of one hundred and ten thousand square feet.

Quantity of Sewage.—Normally about twenty million gallons of sewage reach the plant per day. At times of heavy rainfall the flows are greatly increased and have approximated rates of one hundred m. g. d. on several occasions.

FIG. 2.—Erie Sewage Treatment Works. Digestors, Sludge Beds and Sludge Circulating Station in Foreground.

In the original design of the plant, no provision was made for bypassing or limiting the flows that entered it and after several weeks' operation, it was necessary to shut down the plant and to construct a large overflow weir on one of the interceptors. Although this has alleviated conditions somewhat, excessive flows are still received at the plant and it is planned in the near future to install a valve in the plant interceptor just ahead of the screen chamber.

In addition to controlling the amounts of sewage being treated, this valve will provide means for shutting down the plant in case of emergency. At present, when repairs are made to the bar rack, it is necessary to divert the flow by changing stop planks in sewers about the city and by damming off the remaining flows with sand bags. This requires several days and con-

siderable labor; also, a like period of time and amount of labor are required to place the plant in operation again.

The writer is of the opinion that every plant should have means at hand for controlling the incoming sewage and that every device should be provided with suitable bypasses or they should be installed in duplicates with provisions for taking out of service any device for repairs, etc. This is especially true where mechanical devices are employed.

Quality of Sewage.—To date, the sewage would be termed rather weak and fresh with little industrial wastes present as shown by the following data:

Approximate Analysis:	
Settleable Solids, Cc. per Liter, 2 Hours	3.9
Suspended Solids, Parts per Million	106
B. O. D., 5-day 20° C., Parts per Million	87
Dissolved Oxygen, Parts per Million	5.3

Plant Interceptor.—In entering the plant the interceptor makes nearly a ninety-degree bend. This caused currents and eddies to be set up in the screen chamber, with the subsequent deposition of most of the screenings on one-half of the bar rack. These eddies also carried most of the grit with them so that one detritor received an overload, whereas the second received little if any grit.

To correct this uneven distribution of screenings and grit, the shape of the screen chamber was changed from rectangular to a shape more closely resembling the interceptor. This was accomplished by concreting in the sides, thus eliminating all pockets. This construction effected considerable improvement, but to eliminate the trouble completely it was necessary to install an adjustable deflector at the entrance of the screen chamber. This deflector resembles a rudder which may be turned to any desired angle and locked into place by means of a contracting brake band acting on a drum.

Bar Rack.—The bar rack was one of the major difficulties that required correction, so the operation of this device will be covered in detail. This rack is ten feet wide and had three-fourths-inch clear openings. It is cleaned mechanically by a raking device actuated by means of floats. The screenings were deposited on an endless belt conveyer from which they were stored in a large hopper prior to final disposition by incineration.

Originally it was estimated that we removed about one cubic foot of screenings per m. g. of sewage treated.

In addition to rags, paper, etc., of which screenings generally consist, we received a good many tin cans; five-gallon oil cans and occasionally thirty-gallon oil drums; wash tubs; automobile seats; Christmas trees, etc. At one time we received a harness, but in this case the donators kindly left the horse and buggy out of the sewer.

Original Installation.—As originally installed, there was a drop of nine inches between the screen chamber and the influent channel to the detritors. Due to this difference in elevation only about the bottom eight inches of the screen were in use and the velocity of the sewage at the bars was extremely high. The high velocity wedged the screenings into the bar spacings so tightly that an undue load was placed upon the raking device. Also, due to the small area of the rack in service, a high differential head was rapidly built up, which likewise overloaded the raking mechanism. On several occasions the rake was stopped due to cans being wedged into the bars.

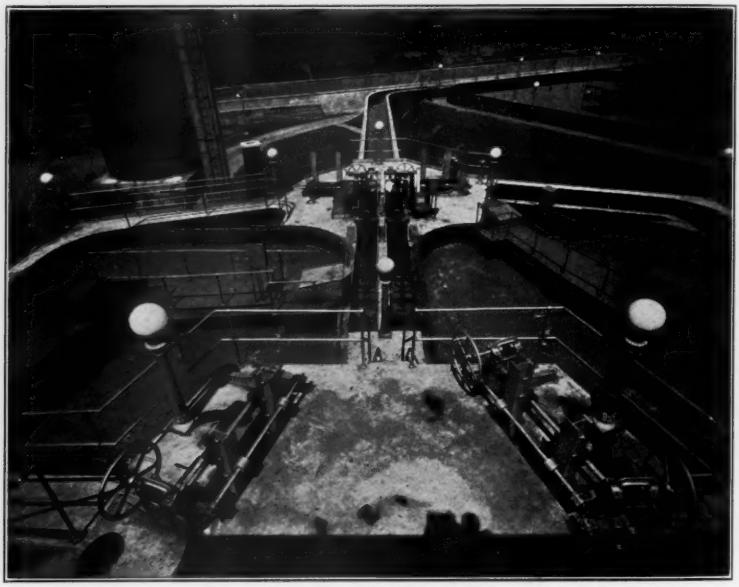

FIG. 3.—Erie Sewage Treatment Works. Detritors and Grit Storage Tank.

To correct these features a twenty-inch stilling wall with an adjustable weir plate was installed back of the rack. Also, the raking mechanism was completely rebuilt and strengthened throughout.

As a result of these changes, about three feet of the rack is in service and the screenings are floated more or less gently onto the rack, thus overcoming all wedging effect. This total area is not packed tightly enough to prevent sewage passing through, so that the raking mechanism is now operated on a differential head of approximately two inches. In making the above changes we increased the quantity of screenings tremendously. Monthly averages increased from approximately one cubic foot per m. g. to six cubic

feet per m. g. with maximum daily averages going as high as twelve cubic feet per m. g. These enormous amounts of screenings required continuous incineration and we were continually operating the incinerator at low gas pressures, with consequent lack of efficiency of this unit.

One factor that undoubtedly had a very important bearing on the excessive amounts of screenings received was the large quantities of *leptomitus* in the sewage during the cold spring months.

It was finally decided to change the clear bar spacing from $^3/_4$ in. to $1^3/_4$ in. by removing every other bar; this has proved very satisfactory. The quantity of screenings has decreased to 1.77 cubic feet per m. g. for the month of May. Also, it is of interest to note that most of the *leptomitus* passes through this sized opening and settles in the primary tanks. Little, if any, additional trouble has been encountered in the operation of the clarifiers or in sludge pumping due to these changes.

Several interesting conclusions may be drawn from Erie's experiences:

(1) It would seem necessary in the larger plants to install a coarse bar rack with 4 in. to 5 in. clear openings ahead of the finer bar racks to protect the latter devices. The large rack should be hand raked. This will be done at Erie when the valve on the plant interceptor is installed.

(2) Considerable care should be exercised in the design of the interceptor at the plant and the screen chamber proper, to avoid cross eddies, currents and dead pockets.

(3) The hydraulics in the screen chamber should be studied with the object in view of utilizing a fair portion of the rack and excessive velocities of flow onto the rack should be avoided.

(4) Structurally these devices should be heavy enough to withstand successfully considerable abuse or rough usage.

(5) It is believed that the trend has been toward too small clear openings in the bar racks. This is especially true where mechanically cleaned racks, followed by mechanical clarifiers, are utilized. Undoubtedly the reason for this is to avoid difficulties in sludge removal and sludge pumping from the primary tanks. While this system possesses certain advantages, they are more than offset, when carried to extremes, by the extra labor and cost involved in handling and disposing of excessive amounts of screenings. Likewise, the size of the plant and other factors should have considerable weight in determining bar openings in racks.

Original Incinerator Design.—The contractor who constructed the plant submitted as an alternate of the engineers' design a design of an incinerator by a corporation specializing in these devices and this design was accepted by the engineers. In the contract the city was protected by certain guarantees as to capacity, performance, etc.

Briefly, this design provided an incinerator which had a drying grate

area of twenty-five square feet, a burning grate area of five square feet and a combustion chamber of approximately one hundred cubic feet. Two low pressure burners were provided which utilized approximately one thousand three hundred and fifty cubic feet of gas per hour. This device was guaranteed to consume ten tons of screenings, as delivered from the rack, per twenty-four hours.

A hopper with nearly vertical sides was provided which discharged directly into the center of the incinerator. This hopper provided storage for approximately two hundred cubic feet of screenings.

One of the first difficulties experienced was in charging this unit. Although it did not seem possible that the screenings could stick and bridge in the hopper, experience soon taught us that such was the case and if the hopper became partly filled, it was impossible to charge the incinerator. Even under favorable conditions, it required about twenty minutes to get a charge poked into this device. Also, it was believed that some drainage would be effected in this hopper but we found that little, if any, of the water drained from the screenings, consequently the screenings were charged into the incinerator containing from ninety to ninety-five per cent moisture.

A test was run on the incinerator and it was found that only about four thousand six hundred pounds could be burned in a twenty-four hour period. Further, the screenings were not completely burned as the ashes obtained during this test run were wet and foul. As this test indicated that the incinerator failed to meet guarantees by a large margin, it was decided to revamp the device and appurtenances. The manufacturer was called in and after considerable experimentation the following changes were made:

(1) A forced draft was installed.

(2) Part of the chimney was blocked off, thus conserving heat.

(3) Part of the checker work was bricked in, thus retaining more heat in the drying and burning part of the incinerator.

(4) Three additional burners were installed and the original two were relocated. In locating the burners one burner was placed so that the flame passed directly over the burning grate and impinged upon the base of the drying grate.

Experience had clearly demonstrated the unfeasibility of attempting to burn the screenings as delivered from the rack, due to their high moisture content. Therefore, experiments were undertaken to develop a simple means of draining out the excess water. Large garbage cans were purchased and liberally perforated. Tests with these cans indicated a loss in weight by drainage of water of thirty-three per cent in four hours.

Another test was run on the revamped incinerator and it was determined

that, allowing for drainage of thirty-three per cent, the device would handle slightly better than ten tons of screenings as delivered from the rack. On this basis suitable means were provided for draining the screenings, consisting of:

(1) The removal of the storage hopper and appurtenances.

(2) The construction of a drainage floor of concrete immediately above the incinerator. Suitable sewer connections were provided.

(3) The installation of a larger hand-operated charging door.

(4) The installation of a chute leading from the end of the conveyer belt to the garbage cans located on the draining floor.

(5) The purchase of two dozen large garbage cans for storing the screenings. The bottoms of these cans were perforated and a wire basket was placed inside of each can.

The entire installation was walled in, and a stairway and door were provided, entrance being from the rear of the incinerator. For exhausting gases, odors, etc., the blower intake was connected into this room.

Another test was run on the incinerator after these changes were made. Careful checks indicated that a loss of 31.4 per cent by weight could be effected in four hours' drainage in the garbage cans. The incinerator again burned the screenings at a rate slightly exceeding ten tons per twenty-four hours when calculated as screenings delivered from the rack.

At present our method of operation is to keep the incinerator warm at all times and to add screenings from time to time. This method, while not very efficient, requires a minimum of labor. Occasionally when a number of cans of screenings have accumulated, the device will be operated at maximum efficiency for a few hours or until all screenings are disposed of. This scheme of operation has always produced a fine, dry, non-putrescible ash, averaging about 12.5 per cent by volume of the screenings burned.

It is believed that experiences at Erie clearly demonstrate the need of adequate draining or pressing of screenings prior to incineration. If provision is not made for some dewatering of screenings, the incinerator capacity would have to be increased by approximately 50 per cent.

Of the two methods of dewatering screenings, adequate drainage has the advantages of less cost of installation, maintenance and less cost of and simplicity in operation. Longer periods of drainage naturally will effect a further dewatering, but it is certain that drainage alone will never effect as complete dewatering as pressing. However, as there is generally an excess of gas available that is wasted, it would seem practical to utilize some of this gas for evaporating the excess water in the screenings rather than resorting to pressing. The original cost of installing a slightly larger incinerator where drainage is practiced, would be more than offset in the savings effected by the elimination of the press, etc. Of course, it should

be borne in mind that other uses for the excess gas may be developed, such as furnishing power by means of gas engines.

Detritors.—The operation of the detritors has been very satisfactory. It took a little time to get uniform flows through these devices and at first, as noted elsewhere in this paper, one of the detritors received practically all the grit. This latter condition was nearly corrected by the deflector in the plant interceptor. A little work on this item still remains to be done.

Quantity and Quality.—To date we have only averaged about 0.4 cubic foot of grit per m. g. of sewage treated. Of this 0.4 cubic foot, about one-half is grain from mash, a by-product of illicit distilling operations.

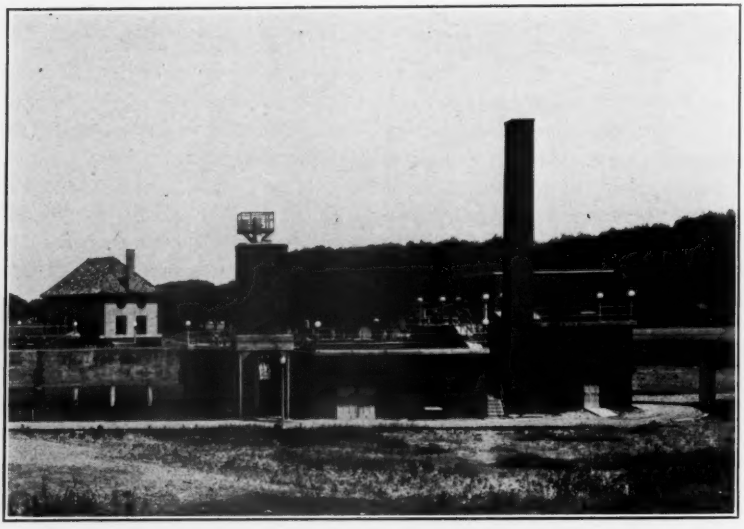

FIG. 4.—Erie Sewage Treatment Works. Building Housing Coarse Bar Screens and Incinerator.

Analysis indicates organic matter, measured as loss on ignition, of 54.6 per cent. Due to the nature of these mashes they decompose rapidly and upon standing in warm weather become exceptionally foul. We have found it impractical to store the grit during warm weather, so our practice is to empty the storage bin and bury the grit every day. Experiments will be undertaken shortly to determine the practicability of incinerating this material. The detritors are operated intermittently during normal flows and continuously during heavy flows from storm run-off.

Clarifiers.—No difficulty has been experienced in operating the clarifiers and they have shown fairly good efficiencies based upon percentages of

removal. Of course, as the sewage becomes more concentrated these efficiencies of removals will become higher.

PERCENTAGE OF REMOVAL	
Settleable Solids, Cc./L., 2 Hours	89
Total Suspended Solids	42
B. O. D., 5-Day, 20° C.	35

Various schedules of operation of the clarifiers have been tried and at present these devices are operated continuously. Various sludge pumping schedules have been experimented with and at present we are pumping primary sludge six times per day. The total pumping period is about five hours. The sludge as pumped from the clarifiers averages about 8 per cent solids. Grease is removed from the top of the clarifiers by means of a skimming arm located on the bridge of the clarifier. It is flowed to a small skimming tank where it is skimmed by hand into containers and allowed to drain. Final disposition is effected by incineration. We remove about 0.3 cubic foot of grease per m. g. of sewage treated.

Digestors.—This step of the process has been exceptionally successful; digestion has been very rapid and at no time have we been troubled with foaming or scum formation. Care was taken in starting these tanks to maintain optimum pH conditions; about twenty-five tons of lime were used in the first three months and no lime has been used since the first of April. We were fortunate in the time of placing the plant in operation, as, in early October, the sewage was warm and at no time has the digestion tank temperature dropped below 69° F. The maximum temperatures obtained have been 78° F. At this writing the pH of the digesting sludge is 6.8; temperature is 70° F. It is planned to increase this temperature and to hold it at about 80° F. Evidently the sludge digests satisfactorily with the present pH range.

Quite a bit of sludge has been drawn to the beds and the analysis of this material indicates exceptionally complete mineralization. As applied to the beds the sludge has varied from 9.0 to 13.0 per cent solids and the organic matter measured as loss on ignition has varied from 43 to 50 per cent. The sludge has dried rapidly into a light porous cake without any objectionable odors.

As we have ample digestion capacity, it is planned to use two of the digestors for the active digestion processes and the third as a sludge storage tank. This procedure will simplify sludge drawing, gas collection, etc. The mechanism in the digestor used for storage will not be operated except when drawing sludge. The mechanism in the active digestors will be operated continuously.

During a considerable period of the plant's operation, we were troubled with what seemingly was a heavy overload on the digestors. Prolonged

investigation finally disclosed that this seeming overload was due to an error in constructing the spring overload mechanism.

Contrary to some other experiences, we have found a decided thickening effect on the sludge when operating the digestor-stirring mechanism. It is very possible that the thickening effect obtained on the sludge by the stirring mechanism at Erie might be accounted for by the rate of additions of primary sludge. It has been noted that when only one digestor received the fresh solids over an extended period of time, this thickening effect was either lost entirely or greatly reduced. It is also very possible that storage of the digested sludge will produce fully as thick a sludge as that obtained

FIG. 5.—Erie Sewage Treatment Works. Straightened Channel of Mill Creek, Clarifiers and Digestors on Right, Sludge Beds on Left.

from a digestor that is operating. Experience to date indicates that such is the case.

Gas Production.—As noted elsewhere, the digestion processes have been unusually successful; therefore, we have had more than an ample supply of gas under ordinary operating conditions. The gas is used for incineration, heating of building; digestion tank heating and in the laboratory. No additional fuel is used at the plant and, normally, considerable gas is wasted.

Gas was collected and utilized about three weeks after the plant started operating. At present we are producing about seventy-five thousand cubic feet daily, which is equivalent to 0.6 cubic foot per capita of contributing

population. Analysis indicates that the gas is a trifle high in carbon dioxide which runs about thirty-three per cent.

Due to wide fluctuations in gas pressures, it would seem desirable to install, between the digestors and the furnaces consuming the gas, either a gas holder or pressure tanks. This would insure a uniform pressure when burning the gases and undoubtedly would increase the efficiency of all gas-fired units.

Sludge Disposal.—Through favorable publicity in the newspapers, the public in Erie and surrounding territory has been educated as to the value of the dried sludge as a fertilizer. To date the people have taken all sludge drawn to the beds, removing it from the beds themselves. No charge is made for this sludge. Due to shutdowns of the plant, we will not have a great deal of sludge this year and it is possible that for this year the demand will keep pace with the supply. Also, we are installing a pump to deliver the wet sludge to some vacant land next to the plant site which we wish to convert into lawn. When this is done, our sludge drying problems will be solved for several years. It is planned, however, always to keep a few beds of sludge ahead to meet the local demand.

Operating Personnel and Costs.—The regular force consists of a superintendent, assistant superintendent, one mechanic, one utility man and three operators. The utility man relieves each operator one day a week so that every man in the organization is on a six-day week basis. All regular employees are paid on a monthly rate. During the summer months, and at other times as the occasion demands, the regular force is supplemented by employing additional help which is paid at an hourly rate.

At this time no actual figures are available as to cost of operation, but it is interesting to know that our operating budget has been set at twenty thousand dollars for this year. This is equivalent to seventeen cents per year per person contributing sewage. Even with the largest single item of expense connected with sewage treatment completely eliminated, namely, that of sludge disposal, it will be impossible to keep within the bounds of our budget.

Conclusion.—As this paper has dealt at length with the difficulties encountered in operating the Erie plant, it is possible the impression has been given that an undue amount of trouble has been our lot. This, however, is not true and in fact the reverse is the case, as in the writer's judgment the plant was placed in operation with practically a minimum of trouble and expense. It is estimated that the total cost to the City of Erie of making necessary changes and improvements to date, has only been two-tenths of one per cent of the total cost of the original installation. When one considers that only two items, namely, the bar rack and incinerator, caused any trouble and that these were minor in nature and were taken care of at such slight expense to the city, it is felt that the City

of Erie is to be congratulated in its success in solving its sewage treatment problems.

Discussion

JOHN T. CAMPBELL, of J. N. Chester, Engineers, Pittsburgh: The Erie sewage disposal plant, which has been so aptly and concisely described by Mr. Cameron, is a primary treatment plant as far as the plant proper is concerned and the settled effluent from the Dorr clarifier tanks receives its secondary treatment by being oxidized by the water of Lake Erie.

From the clarifiers the settled sewage is conducted two miles into the deep water of Lake Erie, through a 72-inch concrete outfall laid below the bed of the lake. The effluent is dispersed through a number of small orifices in the top of the pipe at a depth of water 25 ft. below mean lake level.

The land section of the treatment works has been designed for a population of 200,000 and separate sludge digestion was decided on for the reason that it is more flexible than Imhoff tanks, in that either the settling basins or the sludge digestors can be extended, dependent on the type of sewage that reaches the plant. At present the sewage is rather weak or dilute, due to the fact that meters have not been installed on domestic users. The population before it reaches 200,000 may, however, be metered, which will change the character of the sewage coming to the plant and thereby change the present ratio between the settling basins and the sludge digestors.

The second reason for the selection of this type of plant was that very little difference in head was available between the interceptors and the lake level. An Imhoff tank construction would have necessitated considerable construction below lake level at greatly increased cost and rock would have been encountered.

The plant, as Mr. Cameron has pointed out, is a mechanically operated one, machinery being employed in all of the units. However, the operation of this plant is remarkably efficient in that only six men are employed during the three shifts of the day—the first shift, running from 8 A.M. to 4 P.M., is manned by the superintendent, assistant superintendent, utility man and a laborer. The second shift from 4 P.M. to 12 o'clock midnight is operated by one laborer and the third shift from midnight to 8 A.M. also is operated by one laborer. This force will have to be supplemented at times when the sludge beds are cleaned, but so far this has been unnecessary, for, as Mr. Cameron has pointed out, the sludge on the beds, after it has dried, has been taken away by people for use on their lawns, gardens, etc. After a large sized sludge pump, which has been ordered, is installed, vacant land next to the plant, owned by the Commonwealth of Pennsylvania, will take care of all of the sludge for several years to come. There is also the possibility that this sludge can be used on the peninsula to benefit the soil, in which case Erie will have no sludge problem for many years to come.

If this plant were redesigned in the light of our present experience in placing it in operation, very few changes would be made. These would consist, as Mr. Cameron has pointed out, of the installation of a coarse bar rack with clear openings of 4 or 5 inches, ahead of the finer bar screens, and duplication of the bar screen so that one screen could be shut off for repairs without diverting the sewage. The second change would probably be the installation of the grease skimming tank in the open. This skimming tank is now located in the basement under the detritor mechanism and screen, and on account of the large quantity of mash it is a difficult matter to keep the room in which this skimming device is installed free from odor. The third change which might be advisable would be a receiving tank for drawing the sludge from the clarifiers. The sludge could be inspected at this point and properly conditioned with lime before it is picked up by the sludge pumps and discharged into the digestors. At the present time the suction of the sludge pumps is a closed cast-iron line directly from the clarifiers and the discharge is a closed line from the pumps to the digestors.

The plant started with practically a minimum of trouble and what trouble occurred was due principally to the intercepting sewers bringing down material which was not anticipated, but which nevertheless had to be taken care of, such as barrels, large tin cans, tree trunks, mattresses, automobile seats and bales of wire. How these materials ever got into the sewage is a matter of conjecture but it would seem that the sewer system is being used as a rubbish dump by opening the manholes and throwing in anything which the residents wish to get rid of.

In conclusion, I would state that much of the credit for the present smooth operation of the plant is due to Mr. Cameron, and we feel that as long as he has charge of this plant, it will continue to run smoothly.

C. F. WERTZ, of G. B. Gascoigne, Cleveland: What type of incinerator do you use?

MR. CAMERON: A Midwest Incinerator. This company has gone out of business.

MR. WERTZ: Does it have a flat drying hearth?

MR. CAMERON: It drops 30° down to the burning hearth.

MR. WERTZ: What fuel do you use?

MR. CAMERON: Sewage gas.

H. M. BEAUMONT, Philadelphia: Are the screenings put on the burning hearth by hand?

MR. CAMERON: By hand.

WELLINGTON DONALDSON, Fuller & McClintock, New York: Do you have any trouble burning screenings?

MR. CAMERON: Our biggest trouble is the odor. When we let the drainage go through the grids and they get hot we have odors. Since the screenings have been fairly dry, we have had no trouble with odors.

MR. DONALDSON: What is the temperature?

MR. CAMERON: Around 1700° F. If you do not get temperatures up to 1300° you do not have much success. You must have around 1800° to eliminate odors.

MR. WERTZ: When you use cans and the reduction is 33 per cent is that the actual moisture?

MR. CAMERON: Yes.

MR. WERTZ: What would represent the actual total difference in per cent of moisture when you drain it in cans?

MR. CAMERON: The screenings prior to draining contain from 90 to 95 per cent moisture. After 4 hours of draining they contain about 85 per cent moisture.

BY A MEMBER: Did you ever experiment with an electric filter?

MR. CAMERON: No, I did not.

MR. CAMPBELL: In this plant it would not be advisable to do anything more than to drain off the moisture. We use sewage gas and it is more convenient and cheaper.

MR. FREEBURN: What is the capacity of the incinerator?

MR. CAMPBELL: $10^1/_2$ tons per 24 hours.

The Hourly Variation of Indianapolis Sewage

BY C. K. CALVERT

Superintendent, Indianapolis Sewage Treatment Plant

It is well known that the character of sewage varies almost from minute to minute. There are well recognized daily, weekly and seasonal cycles more or less regular, and affecting both the volume of sewage and its organic concentration. The daily and weekly cycles are more noticeable in purely residential communities. As industrial wastes increase, the cycles are flattened out except as the seasonal demand for certain goods, or the necessity for packing certain crops at special times, becomes a factor.

Even temporary changes in the volume or character of sewage may be of importance to the satisfactory operation of a sewage treatment works, especially if that change is on account of wastes inimical to the biology of the process, but, ordinarily, only such changes as persist for a considerable length of time are of interest to the operator.

The capacity of a sewage treatment plant is stated in terms of m. g. d. with no respect for the daily peak which occurs regularly, and in volume, concentration, and duration is sufficient to affect the extent of treatment given to a considerable volume of sewage.

The information contained in this paper has been collected during five years of operation of the Indianapolis Sewage Plant, at which the process consists of clarification and activated-sludge treatment. The sewage treated carries considerable industrial waste as is shown by the 5-day B. O. D. figure which, on an average, is 0.36 lb. per capita per day, or twice that ordinarily considered the domestic load. In addition, there is a large daily peak both in volume and in concentration.

In Figure 1 it is shown that the average daily rate of flow is exceeded for about twelve hours. On the basis of the designed average aeration period of 5.5 hours some of the sewage entering the plant during the day is hurried through aeration in 4.5 hours. Figure 2 shows the concentration of organic nitrogen by hours, and it is seen from the curves that the greatest concentration of organic matter coincides with the greatest flow so that the strongest sewage receives the least treatment. The returned activated sludge has some reserve power, perhaps, and the effluent does not show a peak relatively as high as the influent.

Figure 3 shows influent and effluent concentrations of four sewage constituents, hourly from Saturday through the second Sunday, during dry weather. The effluent samples are set back in time to correspond with the influent. The chloride concentration of the influent is, of course, reflected in the effluent, though the radical changes often found in the former are

smoothed out for the most part in the latter by mixing in the aerators. There is very little short-circuiting since the peaks in influent and effluent check very well with the theoretical detention period in the aerators.

The total organic nitrogen and oxygen consumed graphs are especially interesting. (Note that the latter changes scale from influent to effluent.) In both of these determinations the irregularities and daily peaks in the influent do not show up in the effluent until Wednesday. The treatment process is able to handle the heavy loads imposed by the daily peak with no particular sacrifice of quality of effluent. After Wednesday, however, the daily peak is reflected in a small measure in the effluent. This can mean only one thing—the weak sewage received over the week end has allowed the sludge time to recover and build up a reserve for the next week. Every

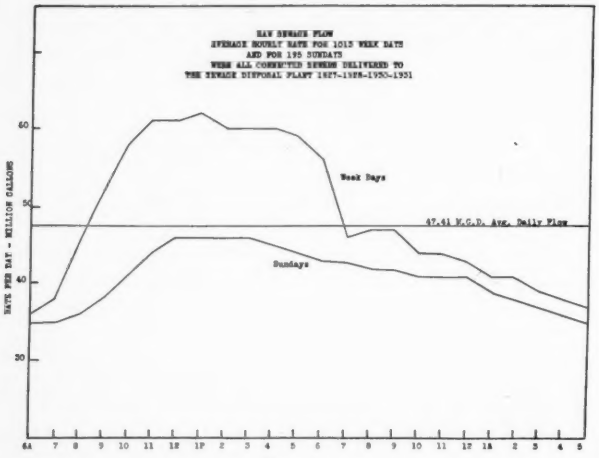
RAW SEWAGE FLOW
AVERAGE HOURLY RATE FOR 1015 WEEK DAYS
AND FOR 195 SUNDAYS
WHEN ALL COMMUTED SEWAGE DELIVERED TO
THE SEWAGE DISPOSAL PLANT 1927-1928-1930-1931
RATE PER DAY - MILLION GALLONS
60
50
40
30
Week Days
47.41 M.G.D. Ave. Daily Flow
Sundays
6A 7 8 9 10 11 12 1P 2 3 4 5 6 7 8 9 10 11 12 1A 2 3 4 5

FIG. 1.

operator of an activated-sludge plant has noted the effect of Sunday, and many times, when operating difficulties are encountered, has welcomed an extra holiday which meant weak sewage and a rest period for the sludge.

The lower graph, showing suspended solids, gives evidence also of the progressive effect of the weekly load but in less degree, which is partly on account of the great difference in scale used for the influent and effluent.

During February, March and April, 1931, nineteen sets of samples were taken of the influent at 6 A.M. and 10:30 A.M., and an equal number of the effluent, timed so that direct comparison could be made. That the effluent samples represented the influent is shown by the chloride figures which average, influent 167 p. p. m. and effluent 158 p. p. m. for the strong

sewage samples. The hours of sampling were chosen to represent very weak and very strong sewage.

Samples may be taken from a sewage treatment plant timed so that disproportionate removal percentages may be indicated. It is the practice in Indianapolis to use 24-hr. composite weighted samples in every case possible, and in the case of determinations like B. O. D., samples for which cannot be stored, the samples are collected from the effluent at a time when the strongest sewage is being discharged.

Table I contains the average of the figures resulting from the work referred to above. The samples were taken at a season during which opera-

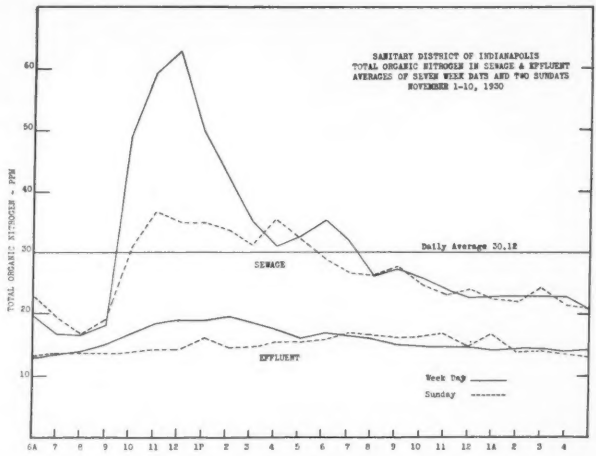

FIG. 2.

tion is most difficult and should not be taken to represent general plant efficiencies. For comparative purposes they are satisfactory.

TABLE I

SANITARY DISTRICT OF INDIANAPOLIS SEWAGE DISPOSAL PLANT. SAMPLES OF RAW AND TREATED SEWAGE TAKEN TO CORRESPOND WITH THE HOURS INDICATED. AVERAGE OF NINETEEN SETS OF SAMPLES TAKEN DURING FEBRUARY, MARCH AND APRIL OF 1931.

	6:00 A.M.		10:30 A.M.	
	Raw	No. 4 Aerator	Raw	No. 4 Aerator
Suspended Solids	131	29	326	45
Oxygen Consumed	46	16	182	23
Biochemical Oxygen Demand	130	17	478	37
Total Organic Nitrogen	19.5	13.2	55.6	18.8
Dissolved Oxygen	0	3.8	0	2.4

The sewage entering the plant at 10:30 A.M. is from 2.5 to 4 times as strong as that entering at 6 A.M. as measured by the determinations shown.

For these particular tests, the time of treatment and air used was maintained the same for the weak and strong sewage. In every case the effluent representing the strong sewage is materially less satisfactory, but

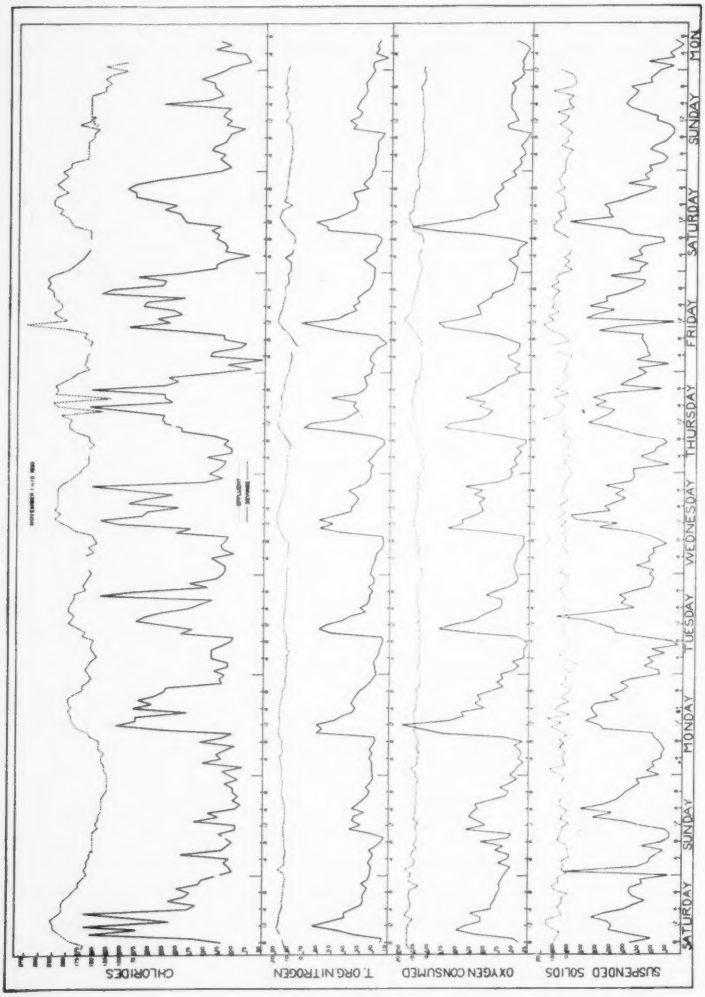

FIG. 3.—Hourly Variation of Sewage and Effluent.

the difference in the weak and strong sewage is much less at the time of discharge than at the time it is received.

In Figure 3 the daily chloride peak is shown. Advantage was taken of

this hourly variation to (1) check the accuracy of sewage meters and (2) determine the rate of flow in the river receiving the sewage plant effluent. At 10 A.M. strong sewage is being clarified and the effluent from the activated-sludge plant is that received during the late night. On a day when only a part of the clarified sewage was being treated at the activated-sludge plant, samples were taken at 5-minute intervals of the (1) clarified sewage, (2) activated-sludge plant effluent and (3) mixture of the two as delivered to the river from the main outfall. Chlorides were determined on these samples and from the figures so obtained the percentages of the two kinds

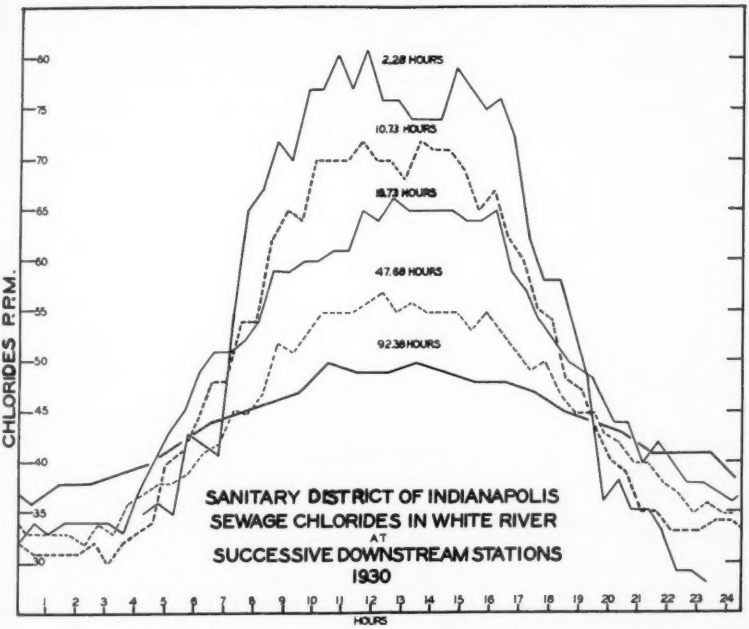

FIG. 4.—Chloride Variation at River Stations, 30-Min. Intervals.

of sewage were calculated. The results showed a 3% error as compared with the metered quantities. This procedure, not at all new, may be used in determining the volume of combined flows when the volume of any one is known, providing some distinguishing characteristic exists. The addition of a dye and the comparison of depth of color has been used for a rough approximation also. The chloride determination has been quite helpful in determining the quantity of certain industrial wastes where direct measurement is not possible.

During the summer months the flow in White River, which receives the

sewage of the city, is quite low. In connection with the biology of the stream it became desirable to know the time of flow between certain points. Samples were taken at half-hour intervals of the stream above the sewage outfall, the sewage outfall, three-quarters of a mile below and at eight other stations, ending about forty miles below the sewage plant. The data so obtained were plotted and the time between points determined by comparing the chloride peaks as well as the duration of the increased figures. In the forty-mile section studied the curves flatten and spread at successive stations down stream. The variation from low to high chloride is from about 40 p. p. m. to 95 p. p. m. at the first point below the outfall, and from 30 p. p. m. to 60 p. p. m. at the station forty miles below. The total time of flow for the forty-mile section was, at the existing river elevation, 3 days, 20 hours and 20 minutes. A comparison of the curves obtained at some of the stations is shown in Figure 4. The last, and lowest curve, is affected by tributary dilution which is not a factor in any considerable degree at the other stations.

Summary

1. There is a wide variation in the concentration of day and night sewage.

2. To insure continuous satisfactory operation of sewage treatment plants, capacities should be such that the strongest daily sewage will receive adequate treatment—disregarding "average" figures.

3. Variation in the sewage effluent during the daily peak is more distinct at the end of the week than at first, due perhaps to sludge exhaustion.

4. Sewage characteristics may be utilized to determine relative quantities of different flows.

5. When the dilution is not too great, the sewage peaks may be followed down-stream and the time of flow determined from point to point.

Remodeling the Lancaster, N. Y., Sewage Treatment Works

Elimination of Excessive Ground Water Infiltration Into the Sanitary Sewer System*

BY HAROLD J. HUBER

Superintendent of Public Works, Village of Lancaster, New York

The Village of Lancaster, which recorded a population of 7040 in 1930, is located about ten miles east of Buffalo in Erie county. Water is supplied to the village by the Western New York Water Company and is distributed to practically all portions of the incorporated area, the average consumption being about 600,000 gallons per day. The sanitary sewer system, which is of the separate type, was built during 1907–1908, and also serves practically all of the buildings within the corporation. It consists of 22 miles of vitrified tile sewers ranging in size from 6 to 24 inch, and is divided into two main collecting systems discharging into a 24-inch sewer leading to the disposal plant, which is at the western edge of the village adjacent to the Village of Depew on the banks of Cayuga Creek. The plant, which was also built in 1908, formerly consisted of two very deep grit chambers, wire screens, two covered septic tanks in parallel, two sewage pumps, Miller-Potter siphon apparatus and distributing devices, and four contact beds, with provision for bypassing all or part of the sewerage to and through the outfall sewer, which also carried the effluent from the contact beds into Cayuga Creek.

When in 1929 the New York State Department of Health after several careful investigations ordered that the Village of Lancaster rebuild its disposal plant and make necessary repairs to its sanitary sewer system to prevent the infiltration of ground water and the resulting impaired operation of the treatment works, very little surprise was manifested by the members of the village board or the Department of Public Works, for the order was not unexpected. For a number of years there had been much complaint from residents of the village that even after a moderate rainfall the sanitary sewers would back up into the cellars of their homes; and it was not unusual after a period of protracted rainfall to press one of the fire engines into service for a few days pumping out flooded basements.

Previous to 1928, there had never been any direct supervision over the sewerage system and disposal plant, the caretaker of which had not been compelled to keep any record whatsoever of its operation. In 1928, however, when a Department of Public Works was established in the village, an unusually severe flood, with its resulting task of pumping out

* *Presented before the Spring Meeting of the New York State Sewage Works Association, Buffalo, June 10–11, 1932.*

cellars and literally digging the disposal plant out of the mud, demonstrated the need of immediate attention to the sanitary facilities of the village and an investigation was ordered.

A preliminary inspection of the disposal plant was the first step in the investigation, and the entire treatment works was found to be in a badly run-down condition. The septic tanks were filled with sludge to the flow line, and the sewage was flowing in rivulets across the top of the sludge mass to the pump wells, from which it was being lifted into the contact beds, the filter material in which had become completely clogged with the solids was carried along with the septic tank effluent. The dosing apparatus was out of order, mainly due to the fact that the masonry between the air-lock chambers was in very bad condition, and leakage from one chamber to the other made proper functioning of the apparatus impossible. There were no sludge beds and the sewage pumps were not adapted to the handling of the sludge so sludge removal had been almost entirely neglected. The pumps, which were of the centrifugal type, had a combined capacity of approximately 500 gallons per minute and both had been badly damaged by freezing. They had been raised from their former location directly on top of the contact bed cover to a point five feet above their former elevation. This change was made, we were informed, because of the fact that shortly after the plant was built, a severe flood had backed the waters of the creek into the plant and completely submerged the pumping equipment, ruining the electric motors. Between the pump wells and the sewer outfall a 15-inch bypass line was discovered, located about three feet above normal water level in the pump wells. Due to the fact, however, that the end of the sewer outfall, which is only about two feet above normal water level in the creek, was equipped with a flap valve, which could not be closed at times of storm flow because the pumping capacity was inadequate, and which if left open allowed the waters of the creek to back into the plant, the resultant conditions during storm periods, when the flow in the sewers often reached 12,000 gallons per minute into the disposal works and the waters of the creek rose from five to seven feet above normal level, can be imagined.

During the winter of 1928 and the spring of 1929 work of repairing the badly damaged plant was begun. A double-diaphragm pump was purchased and the septic tanks were pumped out, washed down with a hose stream, then reseeded and put back into operation. Masonry between the distribution siphon chambers was torn out and rebuilt, bad sections of piping were removed and replaced, and one of the pumps was repaired. It was found impossible, however, to make the dosing apparatus function properly due to the clogged condition of the filter beds and lack of underdrains.

While the plant was in this condition an inspection by engineers of the

State Health Department was made, and on October 10, 1929, came an order to reconstruct the plant immediately. Many conferences and much correspondence with state engineers followed, for due to financial difficulties it was impossible for the village to go ahead with the remodeling of the plant according to the plans outlined by the State. Finally plans were submitted and on July 31, 1931, these plans were approved. The approved plans provided for reducing the depth of the grit chambers, reducing the depth of the distribution channels, increasing the depth of the septic tanks, installing new stone and underdrains in the contact beds, constructing two sludge drying beds, installing a sludge pump and sludge line, constructing a chlorine mixing chamber on the outfall sewer, and in-

FIG. 1.—General View of Disposal Plant Reconstruction. Pumphouse in Right Foreground.

stalling chlorination equipment with provision for chlorinating all bypassed sewage. (Figure 1.)

The grit chambers which, due to their great depth, had acted very much like small septic tanks, had been a source of considerable trouble. Septic action in the accumulated solids at the bottom of the chambers brought great quantities of scum and sludge to the surface, blocking the screens and giving off very offensive odors. Depth of the chambers, which were filled in with stone from the contact beds covered by a concrete slab, was reduced from 9.75 to 1.50 feet. The distribution chambers, which were narrow channels across the full width of each septic tank, each equipped with two rows of ten-inch tile, four in a row, spaced two feet apart horizontally and vertically, were also altered to some extent. Use of the two rows

of openings, and especially the lower ones, had previously resulted in a considerable disturbance of the sludge in the septic tanks, inasmuch as under normal conditions the lower openings only carried the incoming sewage into the septic tanks. The depth of the water in the distribution chambers was reduced from 9.25 to 4.60 feet by plugging the four lower openings into each tank and filling in with crushed stone overlaid with concrete to the level of the bottom of the upper row of holes. The openings retained are at approximate mid-depth of the tanks, and the closing of the lower row of openings has had no detrimental effect on the tank operation, the tank outlet being but 12 inches in diameter. Between the grit chambers and the distribution channel two coarse bar screens have been installed, each made of $^1/_2$-inch galvanized iron bars spaced $1^1/_4$ inches center to center. These screens are manually raked.

The water depth in the septic tanks is maintained by an upturned cast iron elbow on the discharge pipe from each tank. Checking with a field level, it was found that the water level in each tank was approximately three feet lower than that shown on the original plans. Inasmuch as the planned depth was only 9 feet, the tanks were operating at but two-thirds of their normal capacity. A three-foot piece of 12-inch cast iron pipe was caulked into each of the upturned 12-inch cast iron elbows, raising the liquid level in the tanks from 6.25 to 9.25 feet, and increasing the capacity of each tank about 25,000 gallons.

Each septic tank as mentioned above discharges through a valved pipe at mid-depth of the tank into one of two pump-sump wells, which can be cross-connected through a 12-inch pipe equipped with a gate valve. There are two horizontal sewage pumps, direct connected to electric motors, one over each well, and each pump is operated by a float-control mechanism in its well. The pumps have been completely rebuilt, and are estimated to discharge under usual operating conditions approximately 400 g. p. m. each. Normally, they discharge into a concrete channel leading to the distribution siphons, but provision has been made for each to discharge through a 4-inch elevated pipe directly to the creek at times when it is necessary to close the valve at the end of the sewer outfall. When pumping under these conditions, however, the capacity of the pumps is estimated to be but 300 g. p. m. each, due to friction loss in the lines leading to the creek. Although at the time the pumps were being rebuilt, increasing their capacity was considered, it was found that the distribution apparatus will not handle over 400 g. p. m. without being thrown completely out of balance. It was decided, therefore, to rebuild the pumps to their original capacity, and to install an additional pump for use in emergencies. The original pump house, however, was found to be entirely too small to house any additional equipment, so an addition 12 feet square of frame, covered with a metal brick siding to blend as much as possible with the brick walls

of the original building, was built on the north side of the pump house. In this addition was installed a sludge pumping unit, consisting of a centrifugal pump, direct connected to a 25 hp. gasoline engine, both being mounted on a rubber-tired truck. The pump, which has 8-inch suction and 6-inch discharge connections, is of the closed impeller type and is capable of passing a ball $4^3/_4$ inches in diameter. It serves two purposes—that of a sludge pump and also as an auxiliary pump for use in time of storm flow. The pump is permanently connected to an 8-inch line provided with a foot valve in the west pump-sump well. The discharge line, which is increased at the pump from 6 inches to 8 inches, leads out across the sludge drying beds to the bank of the creek and is so equipped with gate valves that it may be used for pumping sludge onto the beds, or for pumping settled sewage directly into the creek. Under test, pumping settled sewage at a total head of 27 feet, the pump discharged nearly 1800 gallons per minute. By removing a flanged 8-inch elbow, a connection can be made with rubber suction hose to standpipes which extend from the cover to within 10 inches of the floor of each septic tank just outside of the pump house, and sludge can be removed in this manner. By taking apart two 8-inch flanged connections, the pumping outfit which, as has been said before, is mounted on a rubber-tired truck, can be hauled out of the pump house and used for pumping out manholes, etc.

Two open sludge beds, each 30 by 130 feet, have been constructed. They are surrounded by a wall of concrete blocks, the top of which is above the flood elevation of the creek, the north wall of the contact beds serving as the south wall of the sludge drying beds. Each sludge bed has three main underdrains of 8-inch tile, 10 feet center to center. There are approximately 12 inches of rock on top of the underdrains, and 8 inches of sand on top of the rock. The stone used for this purpose was selected from that removed from the contact beds and was thoroughly washed before being placed in the sludge beds. The underdrains discharge into an 8-inch header, then into one of the main sewers entering the plant, so that all drainage from the beds passes through the disposal works. Under the ends of the sludge discharge pipes, 3-foot lengths of 24-inch tile have been inserted vertically into the beds, and provided with concrete bottoms. The tops of the tile extend about 5 inches above the sand level in the beds, and a wooden platform has been built at sand level around each tile and extending out about 3 feet from it to prevent washing away of the sand around the tile.

On the outfall sewer, at a point about 50 feet north of where the discharge line from the contact beds enters it, and also so located that it receives all sewage which may be bypassed around the plant, there has been constructed a chlorine mixing chamber, 24 feet by 6 feet in plan, with 4.3 feet of water depth. It is adequately baffled by three over-and-under

baffles, and is so constructed that chlorine can be applied at the inlet end of the tank.

A vacuum-type solution feed chlorinator has been installed in the new addition to the pump house. The chlorinator has a capacity of 100 pounds per day and water is piped to it from the village mains. Chlorine cylinders in use are constantly weighed by being kept on a platform scale during the emptying process. Provision is made for chlorinating regularly at the inlet to the chlorine mixing chamber by means of rubber tubing laid in a 4-inch vitrified tile conduit to the mixing tank. The end of the tubing is equipped with a $5^1/_2$-foot hard rubber grid through perforations in which the chlorine solution is applied to the sewage. If need be, chlorine can be applied by means of a split feed to either or both of the pump-sump wells. This provision is necessary because during periods of flood in the creek the end of the outfall sewer is usually under five or six feet of water, which is prevented from backing into the plant by closing a 30-inch Calco slide gate operated by a handwheel, which has been installed at the end of the outfall, replacing the old flap valve. During such periods, it is necessary to use the sludge pump and the two sewage pumps as bypass pumps, and at such times split feed chlorination of settled sewage is used. In addition to the pumps a 12-inch tile bypass, equipped with a 12-inch gate just outside of the pumphouse door, has been laid from the pump wells to the creek, the end of the bypass in the pump wells being about 18 inches above normal water level. At times of storm flow this 12-inch line relieves the pumps until such time as the rising waters in the creek make necessary the closing of the gate valve. A high water alarm, which rings a bell in the caretaker's house when the water in the pump wells raises one foot above its normal level, has recently been installed. This consists of a 2-inch standpipe in the west pump well, which is reduced to one-half-inch pipe at its upper end, and on top of which has been mounted a "Mercoid Control," or pressure controlled mercury switch. This installation has proven very satisfactory, as it immediately gives warning when the pump wells begin to fill up, due either to a power failure, a pump losing its prime, or an unexpected storm. Since the reconstruction of the plant it has never been necessary to bypass raw sewage, the truth of the matter being that a three-foot rise in the creek makes bypassing of any kind impossible. At such times, therefore, it is necessary to depend entirely on the pumps, and very few if any flooded cellars have been reported, although the combined capacity of the pumps does not exceed 2500 g. p. m.

The plant has four contact beds, each with a surface area of about 3200 square feet, the depth to the full flow line varying from $3^1/_2$ to $4^1/_2$ feet. The old stone in the beds was removed with a crane and clamshell bucket and, with the exception of the contents of one bed which was piled for later use in the sludge drying beds, it was all loaded directly onto trucks, hauled

away and used as a sub-base on mud roads in outlying sections of the village. Although it had at first seemed possible to wash the stone and replace it in the beds, removal of the first few loads showed the impracticability of salvaging it, since the underlying stone, either due to frost action or for some other reason, was found to be of a size entirely too small for contact beds. The old underdrainage system, to which a great deal of the clogging of the contact beds could be attributed, consisted of but one 15-inch half tile line and two short 15-inch branches laid open side downward on the floor of the beds.

Following the removal of the stone the walls and floors were washed down with a high pressure hose stream and inspected for defects. The walls of the beds were not in bad condition, except for numerous holes between beds and in the outside walls caused by the failure of the contractor to remove the wooden form spreaders from the concrete as it was poured. The spreaders, which extended across the full thickness of the walls between the forms, rotted out and left holes through which considerable, amounts of sewage leaked as it was pumped into the beds. The floors, which were laid on a cinder fill placed directly on the surface of the ground, were in bad condition having settled and cracked at many points, particularly at the junction of floor and wall where cracks about three-quarters of an inch wide all around the beds were observed. The floor concrete itself, however, except for the scaling off of the surface, was in fair condition. All remaining pieces of wood and other foreign matter in the walls were carefully chiseled out, then the holes were grouted with neat cement and filled with a strongly proportioned concrete. Bad sections of the floor were cut out and replaced, large cracks were filled with concrete after grouting, and all smaller cracks were first painted over with Inertol; then, after the paint had dried, were filled with a hot waterproofing asphalt, which formed a perfect bond with the Inertol and made a watertight job. When the concrete in the large cracks had dried, these too were given the same waterproofing treatment. Following this the interior of each bed was given two coats of Inertol.

Preparations for replacing the contact filter stone were then made. A ten-foot section of concrete was cut out of the wall of each bed and down to floor level to provide an opening through which the crushed stone could be hauled into the bed. Plank runways were built from the outside ground level to floor level in the bed, and stone was brought in by backing a pneumatic-tired truck across the concrete floor to the outlet end of the bed. From this point underdrains were laid as the stone was brought in, each load being dumped against the preceding one rather than directly upon the underdrains. Very little shoveling was necessary. Sections of tile were laid just ahead of the stone and the bed was filled completely across its width by careful placing of each load brought in. (Figure 2.) As the

stone was required to be of a special size, double screened, the crushing plant was unable to supply more than 18 loads per day, so but one truck was used to haul the rock into the beds. It required but three men to lay the underdrains and grade the stone as the beds were filled, which was for the most part due to the fact that the driver was experienced and could manipulate his truck very well in the limited area to which he was confined and was also very careful in dumping so as not to disturb the stone already piled.

The new underdrainage system consists of 8-inch half tile laid open side down, 4 feet center to center and discharging into a 15-inch half tile header, which in turn discharges into a concrete flume leading to the outfall sewer.

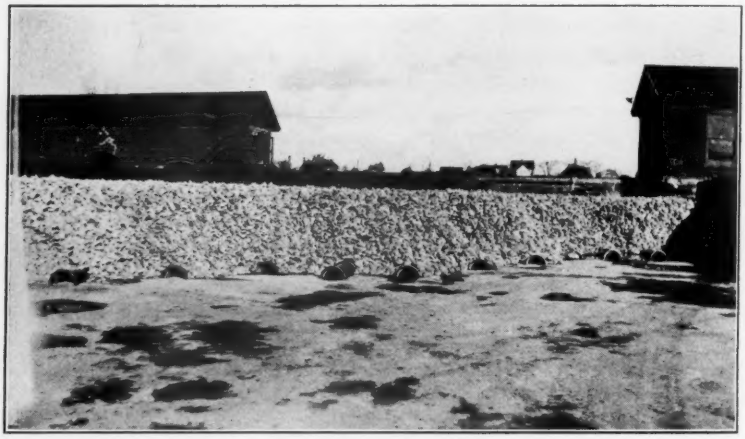

FIG. 2.—Filling Contact Beds with Broken Stone—#4 Size Limestone. Note Underdrains.

About 2000 tons of number 4 size broken limestone were used to fill the beds, and the old distribution system of 12-inch half tile was relaid on top of the stone, new sections being used where necessary. After each bed was filled, the opening provided for hauling in the stone was again filled in with concrete, doweled into the ends of the old wall. The original reenforcing bars, which had been cut at one end only and bent back instead of being removed, were sprung back into place before the concrete was poured, and the wall lost little of its original strength.

The distribution system, which is an automatic, air-operated set of siphons for diverting the sewage to each of the four contact beds in rotation, provides for filling, holding, emptying and rest periods in each bed. The contact beds are now operating on a dosing cycle which maintain the

beds full for about one and one-half hours. It requires about one and one-half hours to fill a bed with the pumps operating continuously, and emptying the bed requires another hour. At this rate of operation each bed remains empty approximately one hour. This is not, however, the average rate of operation as under ordinary conditions there is a period of from 20 to 30 minutes during which the pump wells are filling up and the pumps are not in operation.

At the time of an official inspection on March 4, 1932, by engineers of the State Health Department, a sample collected from the end of the outfall sewer at the creek at the time that a bed was about half discharged showed a residual chlorine of 0.5 p. p. m. with the chlorinator set to apply chlorine at the rate of 70 pounds per day. Since that time the chlorine demand had decreased and at the present time the same residual can be obtained with a chlorine dose of between 55 and 60 pounds per day, dependent on sewage characteristics. Filter bed effluent at the present time contains very little settleable material.

The cost of the entire reconstruction project was about $15,000 for all necessary material and labor. This despite the fact that all unskilled labor was employed, the reconstruction project having been undertaken as a local unemployment relief measure as well as for sanitary reasons. New men were employed every week, each man being given at least six full working days; and despite the fact that it was necessary to "break in" a new gang of men each week and that many unforseen difficulties were encountered, the cost of the project was within our estimate. The entire reconstruction job, from plans to actual construction, was handled by the Lancaster Department of Public Works.

Although the State order to reconstruct the disposal plant also recommended that the village authorities take such action and make such necessary repairs to exclude all ground surface and roof water from the sewerage system, it was financially impossible at the time that the bonds for the reconstruction of the plant were sold, to include sufficient funds for this work. It was a known fact that something had to be done and done soon to remedy the local sewer situation.

The first step in the sewer repair program was the purchase, on approval, of sewer cleaning apparatus. This was of the windlass and cable type, with a set of expanding buckets, and a patented expanding root cutter. The first sewer encountered, although it was a trunk sewer and 15 inches in diameter, was so clogged with roots that a wooden rod an inch and a half square could hardly be pushed through it. Sewers known to be causing trouble, like the one mentioned above, were first on the program, and in the 61 days that the project was carried on, 4.2 miles of sewer lines ranging in condition from almost completely stopped up to temporary clogging due to obstructions, were cleaned out and flushed. The sewer cleaning ap-

paratus proved to be very efficient and the only trouble experienced was with the type of sewer rods furnished. The rods, which were of the hinged-connection type, were used to get the sewer cleaner cable from one manhole to another before the cleaning operation began, and it was found that when pushing them through long stretches of sewer whether obstructed or not the rods would buckle at the hinged joint and, striking against house connections or defective joints in the tile, made it impossible to get them through to the next manhole. Another type of rod with screw joints was then used and no further trouble was encountered.

A most unusual incident during the course of sewer cleaning was the discovery of a cross-connection between a main trunk sewer and an abandoned cellar drain in the heart of the residence district. Complaints had been received by the State Health Department that an 8-inch sewer, located on private property between two dwellings on the main street of the village, was discharging large volumes of sanitary sewage into Plumbottom Creek, the bottom and banks of which had become coated with sludge and gave off, especially at times of low stream flow, very offensive odors. All attempts to trace this sewer without digging it up failed, and finally it was decided to plug it up in an attempt to find its source. Just about this time, however, the sewer cleaning gang dragged a section of the main sewer in front of the two properties between which the old sewer was located, and found several manholes partially filled with sewage due to the partial collapse of a manhole further down the line. Loose bricks were removed with the expansion buckets, and when the water in the manholes went down, it was found that the flow of the old sewer into the creek entirely stopped. Investigation showed that the two dwellings abutting on the old sewer had formerly connected into it, and that upon the construction of the village sanitary sewer system both had connected to the main sewers in the street. The cellar connection from one house to the old sewer was left in however, and when the flow in the street sewer was obstructed, instead of backing into the adjacent cellars and giving warning of trouble, it followed through the 6-inch house connection to and under the dwelling, thence via the old cellar connection to the old 8-inch sewer and into the creek.

Results obtained and conditions found with the sewer cleaning apparatus were a good indication of the general condition of the sewers. Great quantities of sand and gravel were taken out of some sections of sewer, indicating trouble somewhere along the line, and a follow-up gang went to work imimediately digging up and repairing the defective sewers reported by the cleaning gang. Many of the main trunk sewers had been laid through undeveloped land, which was criss-crossed by brooks and drainage ditches and where the greatest amount of trouble was found. Washouts and cave-ins were numerous, most of these being found along undeveloped

"paper" streets where Y connections to building lots had been provided with a sheetiron cover which had rusted away, and those which had been provided with a terra-cotta cover leaked anyhow because the cover had not been cemented into place. Practically all of the tile joints were found to have no caulking whatsoever, those which were caulked being closed on the top of the joint only. Recaulking was done with a cement mortar by digging a bell-hole at each joint, scraping the joint, packing it with oakum and then caulking it with cement. Use of a poured asphalt joint was out of the question as every joint leaked and, judging by the condition of the soil around it, had leaked for a long time. A pre-molded asphalt joint could have been used but as, in this writer's opinion, this type of joint is not as impervious to roots as the cement joint, the latter type was decided upon.

Infiltration into the sewers, however, was not entirely confined to undeveloped areas. Along one state highway in the southern part of the village, which had been paved after the sewer system was installed, over a hundred leaking Y-connections were found. Along either side of the highway was a ditch and at every point where a sewer connection had been extended from the Y at the center of the street to a point outside of the pavement, the bottom of the ditch had dropped out and ground water was entering the sewer. One generous source of ground water was found to be a concrete culvert crossing under the same highway and which carries the water from a large drainage ditch under the road and thence westerly to Cayuga Creek. The culvert is a concrete box, about two feet square, with a concrete bottom about four inches thick. The first indication of trouble at this point was when, during a moderate rainfall, it was noted that water was entering the culvert from the east side—but the ditch on the west side was dry. Investigation showed that the bottom of the culvert had settled away from the sides about three-quarters of an inch, and the water was running through these crevices directly into the sanitary sewer underneath. The State Highway Department has been asked to jack a corrugated metal pipe of the largest size which the culvert will accommodate into and through the culvert, after which the openings between pipe and concrete at the ends of the culvert will be sealed with concrete, eliminating any further possibility of leakage at this point.

Several manholes in undeveloped areas were found to be serving as storm water receivers, due to the settling of the original sewer trench below the surface of the surrounding land, which resulted in a natural watercourse along the top of the trench to the manhole, where in some cases bricks had been removed and in others the action of frost had loosened the bricks which had later fallen into the manhole. Along small creeks many bypasses or tile from manholes to the creek were discovered, these having been installed at points ranging from four inches to two feet above the normal flow line of

the sewer in the manhole. Inasmuch as most of these bypasses were in manholes along sewers which were found to be badly clogged with roots, they were undoubtedly installed to prevent the backing up of sewers during storm periods. Their location seemed to indicate, however, that more water was flowing from the creeks via the bypasses into the sewers than from the sewers into the creeks. Following the cleaning and recaulking process these outlets were closed off.

An interesting fact noted in digging up sewers which entered manholes by means of a drop inlet was that at practically every drop-inlet manhole, the main sewer had settled from three to five inches due to the fact that the ground below it had been dug up for the purpose of laying the drop connection, and probably not tamped enough before laying the sewer above it at grade into the manhole.

Much infiltration of surface water has been prevented by cleaning and widening and in some cases relocating brooks and drainage ditches which are in close proximity to the sewer lines. Most of these, which had not been cleaned for years, were blocked with débris and roots, and in many cases by the caving in of the banks of the ditch. With its flow obstructed, the stream cut a new channel which was, in some cases, directly over the sewer trench, and with the open joints in the sewer below, it was not long before a great amount of water was finding its way down into the tile. At points where this had occurred the stream was diverted away from the sewer by either reopening the former channel, or at points where it was impossible to avoid crossing or paralleling the sewer by enclosing the stream in tile sufficiently large enough to carry the maximum stream flow.

Although, as has been said before, the sewer reconstruction project lasted but 61 days, having been discontinued due to the lack of finances, the beneficial effects of the work done have already been noticed. At the disposal plant one centrifugal pump, rated at about 400 g. p. m. can now handle the entire normal sewage flow, which formerly overtaxed two pumps of the same capacity, and a marked saving in power cost has been effected. No further backing-up of the sewers in areas where they have been cleaned and repaired has been reported, although there have been several severe rainstorms since the completion of the work. Deepening, widening and relocating brooks and drainage ditches has not only resulted in a great deal less infiltration of ground water into the sewers, but has been the means of draining about fifteen mosquito infested swamps, which had been the source of much complaint as they were located in close proximity to the residential section of the village. Much remains to be done—there are about 18 miles of sanitary sewers and 11 miles of storm sewers still to be cleaned, and several miles of sewers to be recaulked, to say nothing of the miles of ditches which are still to be dug, and the unsightly and disease

breeding water holes to be drained. As to the work already done—besides giving work to about 150 men, it is, in every sense of the word, a permanent improvement and something very decidedly beneficial to the entire community.

One great problem remains to be solved—the elimination from the sewer system of roof water which has been permitted to enter it for years, especially in the older sections of the village. No street connections, to our knowledge, have ever been connected to the sanitary sewers, but the many roof connections more than triple the flow in the sewers during storms. Inasmuch as all of the sewage coming into the disposal plant must be pumped, elimination of this added flow is important from an economical as well as from a sanitary standpoint. Investigations have been made and ordinances have been passed from time to time, but not until an actual survey is made and the offenders forced to remove the troublesome roof connections can any real results be expected.

The time is rapidly approaching when a separate and distinct sewer department with its own superintendent and several competent men will of necessity be established in this village, such department to devote its time entirely to repairing, maintaining and improving the local sewerage collection and treatment system, which has during its 24 years of existence had none but the attention required to give immediate relief from stoppages and to keep the disposal plant operating—if pumping partly treated sewage into the creek could be called operation.

The Function of Each Unit of a Sewage Plant*

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This subject might be presented in a comparatively brief summation of facts and figures, as applied to present day sewage works, but inasmuch as every installation requires individual study as to economic utilization of available methods and processes, a general but brief résumé of functions and methods may be in order.

Available Methods.—Sewage treatment methods now available make it feasible to effect practically any degree of purification desired, as required by local conditions, and the diluting water available. Under suitable circumstances, primary treatment only, consisting of clarification by fine screens or sedimentation, may be satisfactory. Where conditions make this inadequate, secondary or oxidizing treatment for the remaining organic matter must follow, by means of trickling filters, sand filters or the more modern activated-sludge process. Germicidal treatment by chlorination is coming into wider use, as the final safeguard, or to supplement any one of the above stages of generally accepted present practice.

Dilution.—The discharge of raw, untreated sewage into streams and harbors is the elementary method of disposal. In spite of our boasted achievements in sanitation, about 85 per cent or more of the sewage of our large cities is still discharged crude, untreated even by screening, into the nearest wet dump. The evil conditions of thousands of our streams is an abomination, and public indignation is being gradually aroused to demand correction. The growing public demand for cleaner streams is plainly evident, and is a factor which demands attention in the design of every treatment works, to meet the probable requirements of the future.

In the last analysis, however, diluting water, in streams and harbors, is relied upon for the "disposal" of the effluent from practically all "treatment works." Its function thus becomes a matter for most careful consideration, both from a sanitary and an economic standpoint. Dilution is not, as the name might imply, simply a means of dispersing sewage, but is the utilization of natural agencies operating in the water courses—oxygen, bacteria and aquatic life—to effect complete purification of the sewage discharged therein, and is generally termed the "self-purification power" of the stream.

Failure to utilize these natural agencies to their full value is an economic loss. Nothing is gained by the erection and operation of artificial works, using the same agencies naturally found in diluting water, to purify the

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sewage to a degree in excess of the purifying capacity of the stream to naturally assimilate and purify it.

Scientific disposal by dilution, however, is not as simple a process as might at first appear, but, on the contrary, is rather intricate. Detailed considerations are beyond the scope of this paper, but are of the utmost importance in most cases, as upon their intelligent application depends the degree of treatment required, and the resultant cost of the treatment works. In general, the function of dilution might be defined as the proper and economic utilization of the purifying capacity of the diluting water to receive and complete the process of purification of the treatment plant effluent, which has been subjected only to the required degree of treatment, dependent upon local conditions, for maintaining the stream conditions within the limits demanded for raw water supplies and for the preservation of public health and comfort, recreation and industrial requirements.

Screens.—The approaches thereto, and the facilities for handling screenings, require careful design and attention in operation, to avoid a nuisance. Many recent installations have been equipped with mechanically cleaned devices, which are generally desirable in larger plants, together with systems for mechanical removal and disposal of screenings by incineration, mastication, burial or otherwise.

Following the machine trend, however, some expensive installations of mechanical screens have been installed in comparatively small plants, which can hardly be justified from an economic standpoint, considering the small amount of screenings handled, the present cost of hand labor, and the results achieved with present available mechanical equipment. In a plant recently observed by the writer, the benefits to be anticipated and justified by the mechanical installation were almost entirely lost, due to too large screen clearances, extremely high velocity of approach, which tended to force rags and other matters through the screen causing serious trouble with the sludge pumps, and the necessity of handling the meager screenings extracted, by hand labor, under disagreeable and inconvenient conditions for removal.

All screenings at best are offensive. In the earliest Imhoff plants, in order to reduce the amount of sludge to be handled in the digestion chambers, screens with comparatively small clearances were used to retain a large proportion of the larger settleable solids. This practice, however, has long since been abandoned, and for years it has been generally conceded that all such matters should be digested in the tanks. Under these conditions, the only function of screening before settling tanks is the removal of the larger floating matters and heavier inorganic substances, to prevent clogging in slots or stoppage in the sludge pipes.

Where the sewage is pumped, the important function of the screens is to exclude objects which might obstruct the pump or interfere with its opera-

tion. Where sludge is pumped to separate sludge-digestion tanks, or pumped from Imhoff tanks, screens with smaller clearances are necessary to avoid troubles with the sludge pumps.

In general, hand cleaning of screens is a disagreeable job, likely to be neglected, and mechanical equipment for complete handling and removal is preferred. While there may be room for some criticism of the present efficiency of mechanical equipment as installed in many plants, improvements will undoubtedly be made in the next few years, making such equipment mandatory, at least in the larger plants.

The latest all-mechanical method, practised in England at the New Ipswich Sewage Works and others, is to flush the screenings removed by the rakes to a so-called stereophagus pump, which pulverizes them and delivers them, as sludge, direct to the sludge-digestion tanks, or returns them to the sewage for tank treatment and deposition as settled sludge. This method, entirely mechanical except for hand extraction of large objects, would seem to offer possibilities for some plants of a sensible solution of the problem of disposal of obnoxious screenings. In some British seashore towns, all screening is eliminated by the use of pumps equipped with cutters on the impeller shaft, which masticate the sewage before discharge to the sea.

At the Moscow, U. S. S. R., sewage works, examined by the writer two years ago, the method of handling screenings was of interest. The screens, designed by Russian engineers, consisted of a series of fixed vertical bars, spaced about 1 inch in the clear, equipped with a motor operated cleaning device, discharging onto a belt conveyor which carried the screenings to a grinder. The masticated screenings fall back into the sewage inlet chamber ahead of the screens, to be rescreened in case of insufficient grinding, and all matters, other than large objects removed by hand, pass on their journey of several miles to the treatment works, where they are handled as sludge. The sewage output from the pumping station is about 40 million gallons per day, and the screenings have been satisfactorily handled in this manner since 1914.

Fine screens have been used quite extensively in Germany and the United States, but have not found favor in English practice. Under some conditions they may serve a useful purpose, particularly where nuisance from floating solids is the principal factor. They are only about one-third to one-fifth as efficient as settling tanks in removal of total suspended matter, and thus cannot compare with sedimentation from an economic standpoint, considering initial and operating costs, and results accomplished. In addition, the screenings are objectionable, necessitating immediate disposal to avoid a nuisance.

Grit Chambers.—Grit chambers are generally essential for all sewage containing street washings and road grit, which would occupy space in

sludge chambers and interfere with sludge digestion and removal, hinder the cleaning of sedimentation tanks, weigh down activated sludge, and cause possible injury to pumps, valves and mechanical equipment. Their function should be the removal from the sewage of the maximum amount of such heavy materials consistent with the production of a comparatively innocuous residue containing not over 10 to 12 per cent of volatile organic matter, so that it may be handled and generally disposed of as filling about the plant, without offense or nuisance. The amount of grit is, of course, widely variable, but is frequently found to range from 0.1 to 0.2 cu. ft. per capita per year, or from 3 to 6 cu. ft. per million gallons of sewage. Grit chamber and sedimentation tank problems have been somewhat complicated in recent years, due to the increasing presence of heavy mash from the home brewing industry, which is productive of offensive odors.

Grit chambers are important units in the sewage plant, the necessity for and the design of which should be carefully studied, with due regard for local conditions and type of subsequent treatment, in each installation. There is greater need for them with activated-sludge treatment. There appears to be an increasing tendency by some designers to provide grit chambers as a precautionary measure, with separate sewer systems as well as with combined systems. This tendency has undoubtedly been accelerated by the comparatively recent improvement in mechanical equipment, providing for the more or less continuous automatic removal and washing of the grit as rapidly as it accumulates. Such facilities, if demanded by the conditions and properly installed, with means for expeditious handling of the residue without nuisance, are a decided advance in grit chamber technique.

But here, also, the popular trend toward everything mechanical must be tempered with judgment. Simplification of plant facilities is a virtue, and the inclusion of units not absolutely essential under given conditions constitutes just one more potential source of nuisance. Grit chambers, with the attendant necessity of the disposal of residue, can be exceedingly obnoxious, at times, and the problem is by no means solved by specifying a mechanical device, unless coupled with intelligent provision for the handling and removal of grit, and adequate ventilation if located in a pumping station or other confined space. At a new plant recently observed by the writer, the benefits rightly to be expected from the substantial investment in the automatic continuous-removal, mechanical device, were nullified by the daily nuisance of hoisting 6 or 8 large cans of grit from a deep chamber, and rolling them by hand for a distance of some 25 feet along a passageway, for loading on a truck, at the front door of a very ornate pumping station building. Lack of ventilation in the grit chamber and screen well was productive of nauseating odors which clung to the clothes for hours.

Skimming Tanks.—The widespread practice of dumping waste oil from garages, machine shops, factories, etc., into sewers, constitutes an increasing problem at sewage treatment works, in many cases making it necessary to install skimming tanks to insure satisfactory functioning of the various plant units. Oil in quantity is detrimental in oxidation processes, slows up digestion, forms an objectionable scum on sedimentation tanks, and clogs fine screens.

Such tanks are now generally being incorporated in the designs for larger plants, in some cases being combined with the grit chamber, as so-called "skimming detritus tanks."

The function of the skimming tank is the removal, by flotation, of the maximum amount of oil, grease and other floating matter. Where the maximum removal of oils and grease is desired, some method of aeration is necessary to separate the oil attached to particles of grit and suspended matters. In a recent German grit chamber installation equipped with air diffuser plates, Imhoff reports the removal of as much as 90 per cent of the emulsified oil in the scum which forms due to the breaking down of the bubbles, and the production of grit practically free from organic matter. The use of pre-aeration in the skimming tank is a forward step, and should improve the efficiency of sedimentation.

Sedimentation Tanks.—Recent sedimentation practice in the United States is generally limited to Imhoff tanks, or plain sedimentation tanks, equipped for continuous mechanical removal of sludge and scum, with sludge digestion in separate tanks. The former still holds its deserved popularity with many engineers, and will in many cases continue to be the choice, particularly for smaller plants, where the combination of settling and sludge digestion in a single unit may be less expensive to construct and operate than separate structures with mechanical appliances, and may require less skilled attention.

Sludge removal from separate sedimentation tanks should preferably be continuous, but if intermittent, should be at such frequent intervals as to avoid septic action.

Sedimentation by one or the other of the above methods is practiced in almost all modern works. Both methods are effective and, generally speaking, give equally satisfactory results. When functioning properly they should effect the removal, by deposition, of practically all settleable solids, about 95 per cent being considered fair efficiency with 2-hour settling period. As sewages contain substantial quantities of fine suspended and colloidal solids not removable by settling, the efficiency of removal of total suspended solids will usually vary from about 50 to 75 per cent dependent upon the strength of the sewage. The removal of settleable solids is generally assumed to carry with them and to effect a reduction of about 50 per cent of the total bacteria. As sedimentation has no effect on

organic matters in solution, the removal of the total organic matter is generally only about 30 to 35 per cent, thus reducing the oxygen demand about one-third.

Secondary Treatment.—The above values represent the average results to be anticipated from the primary or physical processes of treatment by screens, oil separation, grit removal and sedimentation. Now comes the critical question—is further treatment necessary? The proper decision means much to the community and taxpayers, and a small expenditure for engineering research on this question may effect great savings. The question cannot be solved by idealists. The installation of works throughout the country has been slowed up or postponed in many cases, due to extravagant and unnecessary demands for complete oxidizing treatment. Neither can the problem be solved for the best interest of taxpayers by the fee system for design and supervision services based upon a percentage of the total cost, tending in some instances to extravagant and unnecessary expenditures for plant and operation.

Chlorination.—More and more, chlorination is playing an important part in sewage treatment methods as a means of odor control, or under favorable conditions as the sole additional means of treatment following sedimentation. The cost of such equipment is relatively small, and the use of large sized containers has materially decreased the cost of the chlorine. Its utilization and efficiency in odor control has, in numerous instances, permitted substantial savings by location of the plant within city limits, rather than at more remote points, and it may frequently be advisable to provide means for the application of chlorine at screens, grit chambers, pump wells, filter influents, etc. Its particular function in odor control is to check the chemical changes in sewage matter which result in the production of foul odors, especially that due to hydrogen sulphide.

Applied to settled sewage effluents, in amounts to provide 0.2 p. p. m. residual following 10 minutes or greater detention periods, it may be expected to effect a removal or destruction of from 90 to 99 per cent of the bacteria, and a permanent decrease of about one-third or greater in biochemical oxygen demand.

Chlorine application has no appreciable effect on the appearance of the settled sewage or in the further elimination of solids, such as can be effected by oxidizing devices, such as sprinkling filters, sand filters or activated-sludge units.

Recognizing its known accomplishments and limitations, the question of whether or not it will suffice is a nice problem in economics for each particular installation.

Trickling Filters.—Despite the increasing popularity of the activated-sludge process, trickling filters are here to stay, and still remain the cheapest and most satisfactory treatment method by artificial oxidation for the

particular conditions at many plants. With proper application of the sewage by moving sprinklers or fixed sprays, and the presence at all times of free air in the filter interstices, filters can be depended upon, when followed by plain sedimentation in humus tanks, to produce a well clarified effluent, showing a reduction in organic matter and bacteria of as much as 80 to 90 per cent or greater.

The most serious difficulties have been the fly nuisances and odors from sprayed septic sewage. The former objection is now possible of control through systematic filter flooding, arrangements for which should be provided in all modern designs. The odor nuisance can be substantially lessened by the adoption of rotating arms or traveling distributors instead of the favorite method of fixed sprays and automatic dosing tanks. Such devices also have the advantage of operating under lower heads and with more uniform distribution and may produce equal efficiency of output with a slightly less depth of filter material.

The odor nuisance from fixed sprays, however, may now be well controlled by a moderate application of chlorine to the settled sewage prior to its distribution on the filters. Such chlorination is also effective in combating the fly nuisance and in the cleaning of the beds clogged with sludge deposits and organic growths.

Pre-aeration of the applied sewage has been claimed to be effective in the control of odors and in increasing the capacity of the filter. British practice generally presumes that with regulated sprinkling, the sewage can acquire all the needed oxygen in its passage through the filter without any special need for spraying or of pre-aeration.

In this connection, the trickling-filter practice in Moscow, U. S. S. R., is of interest. These filters provide an additional stage of treatment in the Koguhovsky activated-sludge plant, which was placed in service in 1929. Although of 3 m. g. d. capacity at the time of my visit in 1930, and planned for increase to 15 m. g. d. by 1933, it is characterized as an experimental plant. The filters are of slag 4 meters deep with concrete walls and fixed spray sprinklers operated by two Miller siphons. The slag rests on a perforated bottom, which forms the roof of an air chamber over the entire area, with provision, if required, for blowing air therein. As used for further purification of the settled activated-sludge effluent, which has been subjected to a short aeration period of only 30 to 60 minutes, the filters are operated at a rate of 30 gallons per cubic foot of filter material, or about 4 times our customary rate of filtration. They also provide a treatment safeguard in case of upset in the activated-sludge process due to unusual trade waste conditions or otherwise.

Sand Filters.—Intermittent sand filters, properly cared for and operated, provide the most complete treatment of any single artificial process. They are capable of producing a clear, non-putrescible effluent, with re-

moval of organic matters well in excess of 90 per cent and a reduction of 98 to 99 per cent in bacteria.

Loadings up to 200,000 gallons per acre per day for well settled sewage have in some cases been considered permissible, but the larger areas required involve high cost of construction, which generally prohibits their use, except for small communities and institutions. For such plants they provide a simple and efficient method of treatment. With the high efficiency of chlorine in the elimination of bacteria from sewage plant effluents treated to a lesser degree, the high efficiency removal effected by sand filters is seldom warranted in large works.

Activated Sludge.—This process accomplishes, under suitable conditions, results comparable to properly functioning sprinkling filters. As in the latter case, the action is biochemical, the contact of sewage and oxidizing sludge being secured by forced aeration in a tank by means of a direct air supply, or mechanical agitation, or both, whereas with sprinkling filters, the contact is secured by the sewage trickling over the oxidizing growths attached to the filter material.

The process may possess certain advantages in cases of plant locations in close proximity to dwellings, or where land area is limited. In some sections it is being enthusiastically heralded as the cure-all for all sewage troubles, but this is not yet fully demonstrated either from the standpoint of dependable efficiency or economy. Its adoption in Pennsylvania has been slow, there being only one plant so operating at the present time, although three other plants are now projected or under construction.

For the treatment of sewage not overloaded with trade wastes, it may be depended upon, when followed by secondary sedimentation, to produce a well clarified effluent, with a reduction in bacteria and organic matter of 90 per cent or greater, depending upon the period of aeration. It will function without odor or fly nuisance.

At the Milwaukee plant, with about 6 hours' aeration period, the results are said to be as follows:

Production of a clear, odorless and stable effluent.
Removal of at least 95% of the suspended solids.
Removal of at least 95% of the bacteria.
Removal of at least 98–99% of *B. coli*.
Removal of at least 96% of the biochemical oxygen demand.
Effluent will contain 5 to 7 p. p. m. of dissolved oxygen.
Effluent will contain B. O. D. not exceeding 10 p. p. m.
Effluent will be permanently stable, and will not putrify if stored in an open vessel or discharged into a watercourse in which it constitutes the total flow.

The construction of activated-sludge plants to provide for 5 to 6 hours or greater aeration periods with diffused air is costly, and operating costs are high to carry purification to the end points. Furthermore, in numerous

installations the process has been found to be extremely sensitive to changes in the character of the sewage, demanding more or less constant ratios of trade waste to domestic sewage. Skilled supervision is necessary to a far greater extent than with the older processes.

Under these conditions, the use of the process as an intermediate stage between plain sedimentation and the trickling filter, would seem to be a subject for more serious consideration than has been given to it in this country. It has been used in Birmingham, England, for a number of years and as previously mentioned, was selected by the Russian engineers at the new Koguhovsky plant, for Moscow. This plant was projected in 1923, designed in 1927 after several years of experimental work, and placed in operation in 1929. Here it is found that 50 per cent of the organic solids are removed with an aeration period of generally only 30 minutes and not exceeding one hour, in the presence of 8 to 10 per cent by volume of activated sludge. About 1 cu. ft. of air per gallon of treated sewage is used, through a perforated pipe system, which could be substantially reduced by the use of filtros plates or if combined with mechanical agitation.

This effluent after about 1 hour's sedimentation, is applied to the trickling filter at a rate in excess of four times our usual rates. With the B. O. D. of the raw sewage usually exceeding 500 p. p. m. the final effluent from the trickling filters show an organic removal in excess of 90 per cent, with B. O. D.'s of not over 50 p. p. m., nitrates in excess of 20 p. p. m. and a bacteria reduction of 98 per cent. Further purification is provided by means of chlorination, if required, and the passing of the effluent into a fish pond, 3 acres in area, stocked with king and mirror carp, and ducks to assist in the biological cycle.

The combined process would appear to offer a more flexible plant, which is the order of the day, provide the safeguard of trickling-filter treatment in case of upset in the activated sludge due to trade wastes, require only about $^1/_3$ or less of the tank capacity of a complete activated-sludge plant, and about $^1/_3$ or less of the customary filter capacity of a complete trickling filter installation. In addition, odors in the sewage applied to the filters are eliminated, the fly nuisance is said to be reduced and gas production increased, as compared with a typical plain sedimentation-trickling filter plant, due to the addition of the activated sludge to the sedimentation tank sludge.

At Birmingham, a portion of the activated sludge is permitted to be carried forward by the effluent, onto the sprinkling filters, which it is claimed does not deposit on the surface but spreads itself over a large area in the interior, thereby increasing the biochemical action in the beds. So far as I know, the only plant to adopt this combination in the United States is at Decatur, Illinois, which has to deal with a sewage containing industrial starch wastes. Reports of the recently enlarged plant indicate that with a

short period of activated-sludge treatment, the settled aerated effluent can be successfully applied to the trickling filters at 3 times the rate for unaerated sewage.

Sludge Digestion.—The principles and results of sludge digestion are well established. Raw sludge, as deposited in the sedimentation tank is usually yellowish grey in color, has a foul odor, contains about 95 per cent water, and the solids are separated from this water with great difficulty. Acid fermentation sets in within a short period, with production of intolerable odors and nuisances. The function of the digestion tank is to convert this objectionable material, by humification or complete rotting of the organic matters, to a stable material, black in color, free flowing, with an unobjectionable, slightly tarry odor, and with its bulk reduced to 80 or 85 per cent water content in the process of liquefaction and gasification, whereby it occupies only one-third to one-fifth of its former bulk. Its pH value should be above neutrality. Due to its porous nature it gives up its moisture and dries readily, without odors, on drying beds.

Experience of the past 26 years, since the introduction of the Imhoff tank in 1906, has demonstrated that these results can be accomplished with properly designed and operated units, in both Imhoff tanks and separate sludge-digestion tanks. Imhoff tanks possess a distinct advantage in that sludge is admitted slowly and progressively to the digestion compartment by gravity, eliminating the attention required for sludge transfer to separate tanks, and avoiding the troublesome features of supernatant liquid. On the other hand temperature and reactions are more easily controlled in separate digestion tanks. The possibilities of digestion in two stages, by combining the advantages of both arrangements, would appear to merit more consideration than has been given to this subject in the United States.

While neither the principles of digestion and gas production are new—gas was first collected and utilized almost 20 years ago—yet the subject of digestion in closed and heated containers is probably the most outstanding development in sewage treatment during the past 6 or 7 years. At first the interest was centered in the importance of temperature in fermentation and gas production, which begins at about 40° F. and increases uniformly up to about 80° F., and in the realization that applied heat would permit a substantial reduction in digestion space, as compared with the space requirements for slow digestion and winter storage in unheated Imhoff tanks. Intense interest now lies in the economics of gas production and utilization as one of the most important by-products of sewage treatment. The trend toward mechanical equipment, aeration, separate sludge digestion, ventilation requirements, etc., has created a new demand for heat, power and light at sewage treatment works. The results obtained from sludge gas recovery in America and abroad during the past 3 or 4 years indicate that the economics of the facts presented cannot be overlooked and that utilization

of sludge gas for power, heat and light must be considered as an important function of the digestion process. Production of gas of high calorific value appears to vary from 500 to 700 cu. ft. per 1000 population per day for sedimentation sludge, up to as high as 1500 cu. ft. for combined sedimentation and activated sludge. Production at the latter rate, equivalent to about 3 hp. per 1000 of attached population, should be adequate to operate a well designed activated-sludge plant. An important feature of recent developments for power production is the utilization of gas-engine exhaust heat for raising the temperature of the sludge in the digestion tanks, by circulation of the cooling water through the heating coils.

Sludge Drying Beds.—Drying of digested sludge upon specially prepared beds is the most common method of disposal, the dried material being generally used for filling, or by farmers for fertilizing purposes. The function being to provide means for drying all sludge produced, without interference in the digestion processes, these beds are extremely important units of the sewage plant. In many cases the areas provided have proved inadequate.

To function properly they must be built of good, graded gravel, stone or slag, of ample depth, with a heavy top coat of sand, and with liberal underdrainage. The area required depends upon numerous factors and calls for careful consideration.

Glass enclosures expedite drying and are coming into wide use. State health department regulations generally approve a 50 per cent reduction in area, as compared with open beds. In addition, covers permit regular sludge withdrawals regardless of weather conditions, reduce odors in case of bad sludge, and lend tone to the general plant appearance. Under certain conditions, with high cost for land, they may prove to be economical. In the majority of cases, where ample land areas are available, they are more costly than open beds, on the 2 to 1 ratio, and cost more for upkeep, including insurance. As usual with innovations, they have been installed in many cases where their use cannot be justified. Unless close proximity to dwellings, or aesthetics, demand complete coverage, a more logical arrangement for sludge beds for efficiency and economy is a combination of open and closed beds, to afford more flexibility of control and the advantages of each method.

Water Metering as a Function.—Sewage to be handled at the sewage treatment works represents the spent water supply of the community, together with a small percentage of solid wastes. The quantity to be handled includes water wasted, as well as water used for useful household or industrial purposes.

Sewage problems are therefore closely related to water works practices, and studies for economy in design should include closer scrutiny of such practices than is evidenced in many cases. There can be little defense of

the type of economics which permits the construction of unnecessary sewage works to treat the excessive waste experienced in flat-rate water systems. Metering, in many instances, reduces water consumption by one-third, and common sense demands coördination of interests, to the extent of reducing the volume of sewage to be treated at the sewage works.

Metering effects no especial savings in the cost of sludge facilities, which are based on per capita figures, but may secure substantial savings on all liquid treatment structures and processes, including sedimentation, activated sludge, trickling filters, sand filters and chlorination, with resultant decrease in operating costs.

Safety First in Sewage Plant Operation*

BY CHAS. L. POOL AND E. C. JOHNSON

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It may not be amiss or untimely to confine our discussion of operation of sewage treatment plants to one phase of operation, namely, the subject of safety first in operation. The question of safety for operators has not been overly stressed heretofore in our meetings, but this topic ought to be of considerable interest for the many sewage plant operators in our Association and in the Federation of Sewage Works Associations.

We have not ascertained how the operator stands as an insurance risk, but the list of risks of various sorts that he might at some time encounter is rather formidable.

His choice of ways and means by which he might go to his reward ranges from a slow passage via some infection, for which the raw materials are neither remote nor difficult of acquisition, to a rapid route by merely slipping and breaking his neck or drowning, by gassing, or, as we have recently had brought painfully home to us in Rhode Island, by being killed by an explosion.

With the increase in mechanical equipment at sewage plants, it becomes desirable to consider as wide a variety of safeguards for the plant operator as for the usual factory employee, whose safety has long been guarded by legislation and inspection.

Thus, according to the type of sewage plant at which he works, the operator may be subject to the possible hazards of electric shock, carbon monoxide poisoning, poisoning from excess accumulations of hydrogen sulphide or chlorine. Confined tank gases offer a serious explosion hazard, and another is from gasoline getting into sewers from garages.

Carbon monoxide, which accounts for repeated fatalities from running cars in closed garages, may be encountered with the new practice of burning gas at sewage treatment plants, a possibility here being the escape of vapors not having undergone complete combustion. From the gas analyses which we have looked up it appears that carbon monoxide is not, however, present in gas from digested sludge in the extremely dangerous proportions found in coal gas. Sometimes leaks from city gas mains will flood valve pits, etc., with carbon monoxide. The hazards from this source may be slight at most treatment works, but it is worth while for operators to consider this danger, especially since it is quite a common practice for operators (of small plants, at least) to do emergency

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work on other parts of the sewer system or on jobs even less related to their usual work.

Hydrogen sulphide is not generally appreciated as a gas which is much deadlier than carbon monoxide, but it is, for equal concentrations, and furthermore, its odor cannot be depended upon for a warning that dangerous concentrations have been reached. Experiences are not uncommon where a man has gone into a tank, sewer or pit, become unconscious, and upon attempt at rescue, the rescuer has also succumbed. One instance has been reported when a series of four persons met this fate in quick succession. Hydrogen sulphide has been the means in some of the cases, carbon monoxide in others.

Then again it is no light matter, as we can testify, to get badly chlorinated from a leaking tank valve or otherwise, even though chlorine is less dangerous than the other two gases mentioned, in that it gives warning.

The mechanization of sewage plants adds hazards from unguarded machinery, belts or gears, all of which obviously should be protected by proper guards. Clothing should be such that it will not get caught in moving parts.

Many sewage plants are unique in the pitfalls they offer, such as open manholes and sumps, valves and exposed piping to stumble over and get thrown into an awkward, if not dangerous, place, narrow walks with insufficient provision of railings, needlessly uncovered tanks of liquid, or units with abrupt edges to fall off.

Operators, in addition to designers of plants and those in whose power the furnishing of safeguarding facilities lies, can do much toward minimizing this type of accident by avoiding careless practices in allowing many of the faults just mentioned.

One of the things that can probably be called to mind none too often is the need for caution in entering tanks that are imperfectly ventilated, tanks that have been emptied of their contents a short time previously, or for that matter any pit or space that is imperfectly ventilated or which is customarily closed to free access of outside air.

The danger of explosion on lighting matches or smoking is obvious. It might well be mentioned that sparks could be struck by nails of shoes hitting against iron rungs of ladders or by metal tools striking glancing blows on metal or concrete.

Then again, there is the danger of gas poisoning. Someone should always be on hand to check up on the return and progress of men entering such places; no one should ever enter them alone. Where the danger is fully appreciated, as in mines, canary birds or mice are let down in cages before humans enter, these being more susceptible to the gases than humans.

Very recently mention has been made of the use of tomato plants for this same purpose, but it was not stated for which gases the leaves would

droop. The plants are supposed to be even more sensitive than the small animals. We mention the tomato plants because they are so often indigenous to sewer plants.

Victims of hydrogen sulphide poisoning need to be brought out into the air as soon as possible. Victims of carbon monoxide poisoning should immediately and continuously be given artificial resuscitation by the prone pressure method, with which everybody, operators or others, should be familiar to a degree that would enable them to apply it anywhere. The prone pressure method is needed for electric shock, drowning or hydrogen sulphide poisoning.

Gas and electric companies of the larger cities maintain artificial respiratory equipment that might be borrowed in cases of emergency. Operators ought to know where these could be obtained on short notice, also where gas masks or oxygen breathing apparatus might be obtained for emergency use, as, for example, to enter an enclosure where chlorine has escaped. Medium to larger sewage plants would do well to maintain some of this equipment. A hip-pocket device might be mentioned that is cheap and handy. This is known as the self-rescuer and is simply placed in the mouth, the nose being clipped shut. It is good for about 20 minutes, but unless especially charged for carbon monoxide is useless against this gas. Miscellaneous sponges or cloths are of little use, and a precautionary word should be said against the indiscriminate use of any piece of equipment as protection against all gases; the equipment's protective capacity should be ascertained beforehand. The Mine Safety Appliances' All-Service Gas Mask can be used for ordinary concentrations of the gases we have been discussing. Army masks are usually not designed against carbon monoxide.

Cleanliness is the best protection against infections, which may wreak havoc by getting into cuts or scratches, or by invading the intestinal tract through carelessness in handling objects, or food put into the mouth before the hands have been washed in hot water and soap. A good disinfecting rinse is an added precaution.

A first-aid kit ought to be kept on hand, including iodine and sterile gauze. Plants, of course, should be equipped with good washing and sanitary facilities, and with comfortable quarters where men can change their clothes. Showers should be provided wherever possible. Operators ought to make a complete change before leaving the plant, primarily to avoid taking infections home.

This subject of safety deserves thought in design of plants, including ventilation of buildings, pits and also tanks, where possible, against pockets for the accumulation of gases, and also with a view to minimizing the possible damage of, and lessening the likelihood of explosions.

With the equipment available these days there is little excuse for much

of the manual handling of screenings, etc., that brings men unnecessarily into contact with objectionable matter that is often splashed and tracked about.

Apparatus for safety is yet another subject in itself, such as, for example, an aspirating device in use in Germany for removing dangerous gases from sewers before men enter.

This brief discussion was not intended as a comprehensive paper, but rather as a reminder about certain obvious yet important things, and while it is hoped that the impression has not been given that every operator is on the brink of doom, comments on experiences, accidents and near accidents, and on what is being done at various plants would be welcome.

South Essex Sewerage System*

BY BAYARD F. SNOW

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Chapter 339 of the Acts of the Massachusetts Legislature of 1925 created a sewerage district comprising the cities of Salem, Beverly and Peabody, the town of Danvers and certain public institutions in Danvers and Middleton. The purpose of this district, as set forth in the Act, was the construction, maintenance and operation of a system of sewerage and sewage disposal for the district thus created.

The governing board consisted of representatives of each of the four municipalities, the County of Essex and the Commonwealth of Massachusetts, together with a chairman who should not be a resident of the district. Of the seven members of the newly formed board five were engineers. Mr. Karl R. Kennison was appointed chief engineer and was authorized to organize an engineering force necessary for the design and construction of the proposed system. About a year later Mr. Kennison resigned to accept the position of designing engineer with the Metropolitan District Water Supply Commission. Mr. Frederick D. Smith, Chief Engineer of the Sewerage Division of the Metropolitan District, acted as consulting engineer from August, 1926, to the close of construction.

The territory which is included in the district lies almost entirely within the watershed of the Danvers River and the engineering problems of design and construction involved no unusual difficulties because of the topography. The extreme upper end of the system crosses the divide between the Danvers and Ipswich River watersheds and necessitated a 20-foot cut for a short distance and an inverted siphon from one of the institutions.

The general direction of the Danvers River is from northwest to southeast, emptying into Beverly Harbor. The lower river and the harbor separate the cities of Beverly and Salem, each of which is so situated that its sewage could be disposed of at sea without excessive cost. Danvers and Peabody lie westerly from Beverly and Salem and have no sewerage outlet except through those cities. At the time of the creation of the district, sewerage systems were already in use in the three cities, whereas Danvers had no municipal sewerage system whatever. Beverly had built a short outfall sewer into its harbor nearly forty years ago but the outlet was only seven hundred feet from shore and not far from a popular municipal beach. Salem had a system about sixty years old with an interceptor, pumping station and ocean outfall which were added in 1906. Peabody's sewerage system was begun about this same time and was

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connected to Salem's interceptor or trunk sewer, and the combined flow was discharged at the outlet in Salem Harbor. The problem, therefore, was to link up the three existing sewerage systems and provide a common outfall sewer to the designated point in the harbor; to provide a trunk sewer through the town of Danvers and at the upper end of that trunk sewer to connect the Danvers State Hospital, the Middleton Colony, the Essex County Sanitarium and the Essex County Agricultural School. The system thus created, including the Salem-Peabody trunk sewer which was taken over for control by the district, resembles a somewhat distorted and irregular letter "Y" lying upon its side. One branch of the "Y" is formed by the Salem-Peabody trunk sewer, the other and much longer branch by the sewer through Beverly and Danvers built under the supervision of the district's force, while the base of the "Y" represents the outfall sewer from Salem Willows out through the harbor to the outlet.

The trunk sewer through Salem from the Peabody line to the sewage pumping station at Salem Willows is of ample size and substantial structure and will probably continue to serve these two cities for many years. Its condition, however, was indescribably filthy and its carrying capacity was very much less than should have been the case in spite of heavy expenditures for cleaning.

Salem and Peabody have long had trouble with industrial wastes and the history of the sewerage systems of the two cities has been one of repeated efforts to remedy conditions and of bitter recriminations each against the other for the discharge of industrial wastes into the water courses or the failure to maintain hydraulic capacity in the sewers sufficient to enable them to carry the entire industrial and domestic discharge. The wastes from the tanning and associated industries, constituting the major part of the sewage from these two cities, contain large quantities of caustic lime. Settling tanks, screens and various methods of treatment at the tanneries had little beneficial effect and the comparatively inoffensive-appearing discharge, meeting domestic sewage and other industrial wastes, combined with the carbon dioxide and formed a plaster on the walls of the sewer elsewhere. In some places this plaster was reënforced with hair with much the same result as you see on the walls. This was not a sediment, but a precipitate which clung to anything with which it came in contact. The velocity of flow had little effect other than to wash away clinging grease and hair and make the deposit more definitely a calcium carbonate.

This chemical reaction took place throughout the entire length of the trunk and outfall sewers and scale even formed on pump impellers and in other unlikely places. In the case of the 30-inch cast iron outfall sewer, which had then been twenty years in service, the hydraulic capacity was found to have been reduced to that of an 18-inch pipe. Examination

of the outfall at a point just outside the pumping station showed laminated deposits of this limestone-like material alternating with layers of grease, hair and fleshings. Numerous experiments were made in the effort to determine the extent of these deposits and the practicability of cleaning the outfall sewer. There was approximately a mile and a half of this 30-inch pipe extending out into the harbor, and because its condition was such that it was impossible to pump all of the sewage through it, bypass gates were opened almost daily, permitting discharge into the river and upper harbor. Nevertheless, it would have been a serious matter to have plugged this sewer in any attempt at cleaning it.

One of the experiments which may be of interest involves the use of oats. Three spherical canvas sacks were made and filled with dry oats. These sacks which were made after the same pattern as a base-ball cover and were 22, 24 and 26 inches in diameter, were placed in the outfall sewer in that order. The pumps were then started and after a suitable period of time the 22-inch sack was picked up at the outfall. This sack showed considerable discoloration from the rubbing on the sides of the sewer, but had not been damaged. A few minutes later the 24-inch sack also appeared. This one showed more effect of abrasion and had one three-cornered tear which, however, was not sufficient to cause it to lose much of the contents. The third sack was not collected, but after a while a considerable quantity of oats appeared. I might add that a canvas sack full of oats will float, but an empty canvas sack when it is thoroughly wet will sink.

An interesting feature in the work of the South Essex Sewerage District was the allocation of construction and maintenance costs. In accordance with the Act which created the district the cost of construction and of maintenance was allocated to the member units of the district, $^2/_3$ in proportion to their respective sewage flows and $^1/_3$ in proportion to their respective valuations. For example, the new trunk sewer was constructed for the use of all members of the district. Two-thirds of the cost of that trunk sewer was divided among them in proportion to their respective sewage flows and $^1/_3$ in proportion to their tax valuations. Similarly, the new pumping station and trunk sewer in and through the city of Beverly were constructed for the use of Beverly, Danvers and the institutions and the cost of such construction was divided between them in accordance with these factors of sewage flow and valuation. It is evident, therefore, that it was necessary to obtain the measurement of the flow of sewage with a considerable degree of accuracy in order to avoid an unfair division of the cost. When the work was first started an attempt was made to ascertain these sewage flows for the years 1926 and 1927, but it was soon found that no trustworthy figures could be obtained. There were two venturi meters in the trunk sewer at the Salem-Peabody line and one

would naturally expect that the records of these meters would give a trustworthy indication of the flow. These meters were below the general level of the sewer to insure their running full at all times. The recording mechanism was located in manholes under the sidewalks. Conditions were not conducive to good registration and mechanical difficulties were fairly frequent. These were 30-in. × 12-in. tubes, but so great an accumulation of carbonates had formed that a 9-in. cleaner could only be pulled through the throat section after repeated attempts and the deposits elsewhere were thicker than in the throat. It is easy to see, therefore, that the records of these meters were useless.

Similarly, the 30-in. × 15-in. venturi meter tube at the Salem pumping station was coated with deposits to such an extent that its registration was approximately 55% in excess of the true flow. This figure as determined by measurement of the deposits in the tube was checked independently when a new meter was installed. The quantity pumped at this station was dependent on the capacity of the centrifugal pumping units and the head against which they operated. In the course of construction it was necessary to remove the venturi meter tube and make further alterations in preparation for the construction of the new outfall sewer. At this time the condition of the old tube was discovered. The 15-in. throat had a deposit of hard, smooth carbonate which reduced its diameter to $12^1/_4$ inches. Thicker and more irregular deposits had formed elsewhere in the tube where the velocities were not so great. From careful measurements taken at this time it was determined that the previous normal rate of pumping which had been recorded as between 11 and $11^1/_4$ m. g. d. had actually been from 7 to $7^1/_4$ m. g. d. Later the pipes were connected, a new venturi throat was installed and a new recording instrument was connected. With these facilities for measuring and with the same pumping conditions, a very close check was made on the accuracy of the computed correction factor.

This work was done in the spring of 1926, but since it was impossible to pump the entire flow of sewage from the cities of Salem and Peabody through the old force main, much of the flow had to be discharged at other points and it was impossible to get a record which would be satisfactory for use as a basis of allocation of costs. Not only were gates opened when rates of flow exceeded the discharge capacity of the system, but they were opened at night to permit men to do such cleaning and removal of deposits as was possible.

Later, when the new force main was put in use, the entire sewage flow of these two cities was discharged through this pumping station and an accurate measurement made by the newly installed meter. To permit equally accurate measurement of the Peabody sewage a meter chamber was constructed under the street surface at the Salem-Peabody line and a

30-in. × 15-in. venturi tube was installed. This was a split-tube venturi, made by the Builders Iron Foundry, and was, I believe, the first installation of the kind. This tube has a split section immediately down-stream from the throat, one flange being set at an angle so as to permit the removal of the upper half of the tube without disturbing its alignment. In this way periodic inspection of the condition of the tube is permitted and cleaning can readily be done. A similar tube is placed in the Beverly Pumping Station, through which is passed the combined sewage of Beverly, Danvers and the institutions.

At the point in the system where the combined flow from the state and county institutions enters the Danvers trunk sewer it was necessary to install a measuring device. The flow at this point was not sufficient to permit the use of the venturi meter, because of the probability of frequent clogging in any tube small enough to give a reasonably accurate record of the flow. The situation, however, permits measurement through a calibrated flume situated just above a drop manhole. The sewer here is 15-in. in diameter and on a grade of eight feet per thousand. The flume is of parabolic cross section and is on a continuation of the same rate of slope. Since there can be no backing up of the sewage, the rate of flow is a function of the depth in the flume. A float-control elevation recorder, therefore, is all that is necessary to give a record sufficient to determine the flow at all times. In this case, however, we have an attachment to the recorder which converts depth of flow in the flume into rate of flow in gallons per day. We rated the flume by discharging metered hydrant streams into the sewer at a manhole above the meter chamber and found that the relation between rate of flow and depth formed a straight line on logarithmic cross-section paper. I am informed that this flume continues to function as designed, but that there is a tendency for grease to collect, necessitating occasional cleaning. The connection to the float chamber was made through the bottom of the flume and had a grit trap with valves for cleaning. The meter chamber is below the street surface and there can be but little ventilation. In consequence there is considerable dampness and the recording mechanism was housed in a box which was made reasonably tight in order to prevent the dampness from interfering with the records of flow.

At three of the four connections from the institutions small meter chambers were built. In each of these cases there is sufficient head available to permit the use of weirs and recording elevation gauges. In the fourth case, there was not enough head to permit this, but the water supply in this particular instance was metered in such a way as to give a good indication of the sewage flow.

By means of the meters I have described, it is possible to ascertain with reasonable accuracy a sewage flow from any one of the member units of the district and the cost of maintenance and operation can be

divided among them in accordance with the prescribed formula. The sewage from the Danvers State Hospital, for example, goes through a meter chamber before it enters the trunk sewer and joins the flow from the other institutions. The combined flow from these institutions passes through the flume meter and flows through the town of Danvers to the Danvers Pumping Station where it passes through a venturi tube. The additional flow from the town of Danvers at the present time is very small because the only connections are those from houses along the streets through which the trunk sewer passes. The combined flow follows the new trunk sewer and enters the Beverly system, through which it eventually reaches the Beverly Pumping Station where it passes through another venturi meter before it joins the combined Salem and Peabody sewage in the common outfall sewer.

An item of interest to designers and construction engineers was the under-water work, consisting of two river crossings, one harbor crossing and the outfall sewer, over 8000 feet in length and 54 in. in diameter. This under-water work cost about $650,000, and included sections passing through ledge where expensive special equipment was necessary for the drilling and blasting of the rock. The entire construction program cost approximately $1,800,000, and was carried out between the spring of 1926 and May, 1930, with the exception of the remodeling of the old Salem-Peabody Pumping Station. This station was put in operation in 1905 and has several serious defects which should be remedied, but up to the present time, however, it has been impossible to secure legislative approval of the expenditure of the money for this purpose.

Discussion

BY H. W. CLARK

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I am not intending to discuss Mr. Snow's very interesting paper except that portion which touches upon wastes and their treatment by carbonation. Sewer clogging in the South Essex District began to be studied by us about ten years ago and in 1923 a report was made by the Department of Public Health, including one by the writer, concerning the clogging of the sewers by carbonate scale, etc., and a description of a method that might be used to prevent this clogging; namely, carbonation by taking flue gas from the stacks of the different plants and blowing this flue gas into such wastes as contained large amounts of caustic lime.

In 1927 I was called upon by the South Essex Board to study this question further and had as my assistants in this work Mr. G. O. Adams, chemist, and Mr. A. C. Bolde, engineer. All of the plants producing wastes in the District were thoroughly studied, these plants being about

80 in number, consisting at that time of tanneries, glue works, felt works and leather works, but only 15 of these contributed caustic lime in any appreciable amount to the sewers. The total volume of wastes coming from the plants contributing caustic lime averaged about 4,000,000 gallons daily at that time and the amount of caustic amounted to approximately 12 to 14 tons daily, about 60 per cent of this coming from one plant. There was a large amount of caustic both in solution and in suspension and also carbonates, sulphates and chlorides of lime, together with some lime salts of organic acids. Experimental work was carried on showing that all this caustic lime could be removed by carbonation, this being determined by the operation of a small experimental plant. It was also shown that there was a plentiful supply of flue gas at all the plants for this purpose, this flue gas containing from 7 to 12 per cent CO_2. During the work studies were made of all the sedimentation tanks, screens, Dorr thickeners, etc., in use at all the industries and a report was made to the District Board showing what was accomplished by these devices in holding back lime, organic matter, hair, hide, etc., from the sewers.

After this experimental work I recommended in May, 1928, that a small demonstration carbonation plant, capable of treating from 4000 to 5000 gallons of caustic waste daily, be constructed at one of the industrial plants of the District and operated under the supervision of the writer and his assistants. Such a plant was erected at a cost of about $2200 and consisted essentially of a suction pipe connected with a stack of the industrial plant, a soot-removal chamber or filter and a Reed air filter and a cooler. After soot removal, filtering and cooling, the gas was compressed by a Root rotary pump driven by a 10 horsepower motor. The pump had a capacity of 150 cubic feet per minute at a pressure of 10 pounds per square inch. This gas was discharged through a header pipe and diffused in a treatment tank by means of a grid of perforated pipes. This small plant, put in operation four years ago, is still at work and demonstrated that it was possible by this method to eliminate all caustic lime from the wastes. The waste at this particular industrial plant contained about 1100 parts per million of caustic and the carbonated lime has always been free from caustic when the plant has been properly operated. Since that time seven additional carbonation plants have been erected and successfully worked. Some of these need to be enlarged but even now at times the sewage at the Salem pumping station is entirely free from caustic lime and the carbonate scale while still, I understand, being formed to some extent, is being formed very much less slowly than before these plants were operated.

It is evident that some of these plants must be improved and so enlarged that they will take care of the peak loads of waste at certain of the industrial plants and it is quite possible that if this is done no caustic will enter the sewers, or so small an amount that it will be neutralized

by acid wastes, etc., and hence the formation of scale will be entirely prevented.

During the progress of this work we had, of course, many conferences with the owners, managers, chemists and engineers of the various industrial plants producing caustic wastes and a number of criticisms made of the process. I think, however, that every one in the District, managers, chemists and all others, is at the present time convinced that it is only necessary to have these plants large enough and kept in operation properly to prevent any sewer clogging from carbonate scale.

The chemists of the various plants made certain criticisms of the process. Some stated that calcium bicarbonate would be formed in large amounts by this process and more scale would be formed in the sewers than was being formed by the calcium hydroxide. In one instance this opinion was arrived at by consulting chemists of an important plant through experiments with compressed pure carbon dioxide and by a chemist of another plant from theoretical considerations or beliefs. It was proved, however, to the satisfaction of every one that when flue gas containing from 7 to 12 per cent carbon dioxide is used, the reaction is much slower than with the concentrated 100 per cent CO_2 and only an inappreciable amount of calcium bicarbonate is formed.

Another statement by the industrial chemists was that wastes containing sodium hydroxide, as occurred at some plants, needed no treatment. This would be true if there were no soluble lime salts in the mixture of sewage and wastes in the sewer. Unfortunately, however, there was always a considerable amount of such salts present; in fact, examination of 21 samples of the mixed sewage collected at the pumping station of the District proved that this sewage contained on an average 379 parts per million of calcium sulphate and in the presence of lime salts like the sulphate, sodium hydroxide forms an equivalent amount of calcium hydroxide and must be treated the same as calcium hydroxide.

What the Pennsylvania Department of Health Expects of Each Sewage Plant Operator*

BY L. S. MORGAN

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There are several questions which naturally arise in the minds of sewage plant operators in connection with the subject of this paper. First, what legal authority does the Pennsylvania Department of Health exercise regarding disposal of sewage, and, second, what are the main considerations in requiring the construction and efficient operation of sewage disposal works?

The Pennsylvania State Legislature in 1905 enacted what is known as the "Purity of Waters" Act. This statute regulates, among other things, the discharge of sewage into the waters of the State and vests in the Department of Health the necessary authority for enforcement of its provisions. This Act empowered the Commissioner of Health, with the agreement of the Governor and Attorney General, to issue sewerage permits, stipulating the conditions under which sewage may be discharged into the waters of the State.

The "Administrative Code" was enacted in 1923 and amended in 1929. The original Code created the Sanitary Water Board, an administrative board within the Department of Health, charged with the duty of exercising all the powers and performing all the duties vested in the Commissioner of Health, the Governor and the Attorney General by the "Purity of Waters" Act. The Board was also empowered to make rules and regulations for the effective administration and enforcement of the laws of the Commonwealth prohibiting the pollution of the waters thereof.

Pursuant to this authority, the Sanitary Water Board adopted a resolution in 1923, which was amended in 1929, concerning the sanitary conservation of water resources and the abatement of stream pollution. This resolution provided for classification of the streams of the State in accordance with the present degree of pollution and the present and probable future use and conditions of the streams, recognizing the natural power of streams to assimilate inoffensively and dispose of certain amounts of sewage by dilution and the need for artificial treatment prior to the discharge of sewage where such methods are necessary for the control or elimination of pollution.

The Pennsylvania Department of Health has been designated as the enforcement agency for the Sanitary Water Board and it is under this statutory authority that the Department exercises legal jurisdiction over the design, construction and operation of sewage treatment works.

There are two main considerations governing the disposal of sewage. This first consideration is that involving the public health. This standard

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requires the elimination of sewage pollution or its control by treatment to a sufficient degree to (*a*) protect streams used now or likely to be used in the future as sources of public water supplies, (*b*) protect public bathing places and (*c*) eliminate gross nuisance conditions which may indirectly be a public health menace.

The second consideration is that involving the economic and aesthetic aspects. This requires control of sewage pollution for the conservation of streams used for (*a*) the support of animal, fish and other aquatic life, (*b*) sources of industrial water supply, (*c*) recreation and (*d*) navigation.

The above considerations will determine to a large degree the necessity for modification in sewage disposal works and will limit the degree to which sewage must be treated prior to its discharge to water courses.

Public and private authorities responsible for the construction of sewage disposal plants are also responsible to the State Department of Health for the proper maintenance and operation of such works to produce a satisfactory effluent for discharge to State waters.

In the operation of sewage treatment works, it is expected by the Department of Health that each plant operator will attempt to operate his plant so that it will perform in the manner for which it was intended. The duties of plant operators might be summarized in general as follows:

1. To produce a sewage effluent of the required degree of treatment to control stream pollution effectively.
2. To prevent conditions of nuisance in the vicinity of the plant.
3. To keep proper records of plant operation.
4. To make the necessary physical observations and analytical tests to determine the efficiency of each unit of the plant and of the plant as a whole.
5. To create the interest and the good will of the public in the sewage treatment works.

In order to produce a satisfactory effluent, an efficient plant operator will first study his plant to determine the purposes and functions of the various units and will familiarize himself with ordinary operating procedures for his type of plant.

Recently the Division of Sanitation of the New York State Department of Health, under the direction of Mr. C. A. Holmquist, published an excellent bulletin on the "Operation and Control of Sewage Treatment Plants." This publication outlines briefly the purposes and operating procedures of various sewage plant units commonly found in sewage works. In general, these procedures are applicable to the great majority of sewage plants in Pennsylvania.

The following, in brief, are some of the fundamental details of operating procedure for each plant operator to follow, as outlined in the above mentioned report.

Grit Chambers.—Should be cleaned after every heavy storm and at

frequent intervals during dry weather periods. Grit should be buried or dried on sludge beds or, if clean, used for sanitary fill.

Coarse Screens.—Should be cleaned daily or more often if necessary, and screenings buried or incinerated.

Fine Screens.—Usually these are continuously mechanically cleaned. Screenings should be buried or incinerated.

Sedimentation Tanks and Septic Tanks.—Sludge and scum should be removed whenever they accumulate to a combined depth equal to $^1/_4$ the depth of the tank below the flow line. Sludge should be removed when there is an appreciable increase in settleable solids in the effluent; all channels, pipes, weirs, valves, etc., should be kept clean and free of grease and grit; and if more than one tank is available, one unit can be cut out of service in order to effect proper digestion before it is cleaned.

Mechanically Cleaned and Plain Settling Tanks with Separate Sludge Digestion.—In plain settling tanks, settled solids should be completely removed at least daily to the separate sludge-digestion tanks. Septic action, indicated by gassing or an appreciable increase in settleable solids in the tank effluent, should be avoided.

In separate sludge-digestion tanks, the contents should be agitated at frequent intervals to assure proper seeding of fresh solids, in order to afford rapid and efficient digestion. This also lessens possibilities of foaming and excessive scum formation. When heating is provided, the temperature should be maintained at about 80° F. The amount of fresh sludge added daily should not be more than one-twentieth of the amount of ripe sludge in the tank and digested sludge should not be removed in amounts to allow the ratio of ripe to fresh sludge to drop below twenty to one. The pH should be maintained between 7.2 and 7.6.

Imhoff Tanks.—Grease and scum should be removed daily from settling compartments and burned, buried or, under favorable conditions, placed in gas vents. The sides and slopes of the settling compartment should be scraped weekly. The slot must be kept free from obstruction. Direction of flow should be reversed at least monthly where such facilities are provided. Scum in the gas vents should be broken thoroughly at least weekly. It may be broken by a hoe, rake or other suitable tool or by water under pressure; by keeping the scum liquid, or by otherwise working down the scum.

In the sludge compartment, the depth of sludge should be measured at least monthly. There are several suitable methods. In one a pitcher pump is used provided with a suction hose let down through the slot, the hose being gradually lowered and the pump operated continuously until sludge is finally pumped. The length of hose payed out determines the depth of sludge. Weighted blocks or disks, suspended on chains and lowered through the gas vents, can also be used.

Sludge should be removed whenever its depth approaches within 18

inches of the slot in the sedimentation compartment and usually, preferably in small amounts at frequent intervals. It should be removed at a slow, uniform rate to prevent channeling and the subsequent withdrawal of green sludge and liquid. Sludge may be started, if it does not flow readily, by agitating with water through perforated pipes or through a hose immersed through the sludge riser pipe, or by agitating with rods through the riser pipe. After use, the sludge pipes should be flushed out and refilled with water or sewage.

Dosing Apparatus.—Pipes and air lines should be kept open and free from obstruction. When a unit can be cut out of service, a complete cleaning of the dosing tank should be made weekly.

Trickling Filter.—Nozzles should be inspected daily and clogged nozzles cleaned and broken nozzles replaced. The surface of the bed should be kept free from vegetable growths and pooling should be remedied promptly or prevented. Distribution and underdrain systems should be flushed periodically.

Contact Beds.—The surface of the beds should be kept free of solids and vegetable growths. When beds clog so that satisfactory results are not obtained, the filtering material should be removed and cleaned or replaced.

Final Settling Tanks.—Sludge should be removed frequently to prevent septic action and interference with tank efficiency. The sludge depth should be determined frequently and sludge drawn when there is any appreciable increase in settleable solids in the effluent. Sludge should be disposed of on sand beds or by return to primary settling tanks.

Sludge Drying Beds.—Beds should not be filled to a depth of more than 12 inches and preferably much less in cold or wet weather and in no case to such an extent that the sludge cake cannot be removed in two weeks in good drying weather. Wet sludge should never be discharged onto partially dried sludge. The surface of beds should be kept clean and level. All sludge should be removed as soon as it can be handled readily with a fork. Dried sludge may be used for fill or spread on ground where it cannot be carried into a stream. It may also be distributed, if possible, for use for farms and gardens.

Sand Filters.—Beds should not be used continuously, but permitted to rest between applications. Beds should be periodically cut out of service and raked or scraped clean. Pooling should be prevented and this condition indicates that cleaning is necessary. Depth of sand should be maintained by removing a minimum amount when cleaning, and by replacing the sand removed, each year.

Disinfection.—Chlorine should be applied continuously in proper amounts to maintain a residual of 0.5 p. p. m. after 15 minutes' contact. An extra supply of chlorine should be kept on hand, the apparatus should

be inspected daily for trouble or leaks and maintained at a temperature of at least 60° F. during cold weather.

The above mentioned operating procedures should be made a part of the regular plant routine. All mechanical equipment should be maintained in proper operating condition and repaired immediately in case of a breakdown. By so doing, each operator will be doing a part of the work necessary to produce a satisfactory effluent and prevent nuisance conditions.

In case operating difficulties are encountered beyond the control of the plant operator, with which he is not familiar, or for which he does not have a known remedy, an experienced sanitary engineer should be consulted and his advice and directions followed.

Some of the more important reasons for keeping records of plant operation are: (1) to enable the plant operator to furnish reports to responsible officials on plant operation; (2) to serve as a guide for future operation in the light of past experiences; (3) to serve as a permanent record of plant performance to be used in case of damage suits brought by lower riparian owners or property owners in the vicinity of the plant; and (4) to assist consulting engineers in the design of future extensions and additions to the plant or new treatment works.

Each plant operator should keep records of the daily volume of sewage treated, weather conditions, the dates of cleaning various units, the units in and out of service, the amount of screenings and grit removed daily and the method of disposal, the dates of transferring or withdrawing sludge and the volume handled, the depth of sludge in tanks, the temperature of sludge in digestion tanks, daily gas production where gas is collected, the dates of removal of sludge from beds and the volume removed, and the amount of chlorine used daily. Notation should also be made of unusual plant operating conditions and of special treatment provided for particular purposes.

Each plant operator should have sufficient laboratory facilities to enable him to make the necessary analyses for plant control. The type and size of the plant and the operating personnel will to a large extent govern the frequency and kind of determinations to be made.

Any operator provided with the proper equipment can make the minimum number of tests, which should include the Imhoff cone test for settleable solids, the methylene blue test for relative stability, the hydrogen-ion concentration of sewage and sludge and the residual chlorine determination. When facilities are available, additional tests, such as biochemical oxygen demand, suspended solids, volatile content of fresh and digested sludge, dry solid content of sludge, bacteriological examination and others, are highly desirable.

The results of the determinations should be incorporated as a part of the operation records and each operator should *make use* of the determinations *as yardsticks for measuring unit and plant efficiency.*

It has often been said and it is generally true, that a good plant operator can produce satisfactory results with an old sewage plant and a poor plant operator can produce very unsatisfactory results with a well-designed and adequate plant.

Securing sufficient funds for proper operation of sewage works is one of the major difficulties facing plant operators. Some of the reasons for this condition are: (1) lack of interest on the part of the taxpayer in the necessities for proper sewage treatment and control; (2) the final product of a sewage works has no economic value and yields no financial return to those responsible for its control; (3) in general, sewage works are located on sites below the places they serve and serious stream pollution does not affect the health, comfort or well-being of those creating such conditions; and (4) funds to operate such works are generally obtained by appropriations from general taxation and on account of the demands for other purposes, most of which are worthy, the funds necessary for plant operation are not available.

The plant operator and other officials responsible for proper plant control can do much to overcome this situation through general education of the public to the plant needs and they should overlook no opportunity to do this. There is, however, another and rather positive method for accomplishing the same results and that is through the collection of rentals for sewerage service.

In Pennsylvania there is no general sewer rental law enabling municipalities to raise funds for sewage plant operation. However, one class of municipality, namely, third class cities, by the Act of May 4, 1925, may provide by ordinance for the collection of an annual sewer rental for use upon the sewer systems and sewage disposal plant.

By the Act of May 4, 1927, boroughs may adopt ordinances for sewer rentals for the collection of an annual charge for the use of the sewer system but no mention is made in this Act of sewage disposal works.

Municipalities in several other states, having sewer rental laws, particularly in Ohio, have been able to secure improved plant operation through the application of the rental system, using the funds exclusively for plant depreciation, maintenance, repair, extension and operation.

This Association might well give consideration to the advantages to be gained from a general sewer rental act and, if so minded, might sponsor a general enabling act, to the end that improved plant operation will result and our streams be thus afforded a greater degree of protection.

Discussion

MR. FOOTE: I think Mr. Morgan mentioned two important subjects. The first is the matter of keeping records. Both Mr. Cameron and Mr. Campbell made certain adjustments in Erie. We can all bear in mind the importance of keeping operating records from the point of view of enlarging

plants and in cases of possible damage suits. It will save later expense in gathering data.

Another point is one this Association can give considerable thought to and that is sewer rentals. The sewers themselves are generally constructed by the taxpayers. The operation and maintenance of a treatment plant have to come out of the taxes. If, as Mr. Morgan suggested, you make a sewer rental charge then the sewage treatment plant can be made self-supporting and the money which is now spent on plants can be used for other purposes. Frequently plants cannot be constructed because the community is bonded to its limit.

Activated Sludge Practice*

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General Definition

The activated-sludge process has been defined by the Sewerage and Sewage Disposal Committee of the Sanitary Section of the American Public Health Association as one which "consists in the agitation of a mixture of sewage with about 15 per cent or more of its volume of bacterially active liquid sludge in the presence of ample atmospheric oxygen; the agitation to continue for a sufficient period of time to at least accumulate a large proportion of the colloidal substance, followed by sedimentation adequate for the subsidence of the sludge flocculi; the activated sludge having been previously produced by aeration of successive portions of sewage and maintained in its active condition by adequate aeration by itself or in contact with sewage."

From the practical standpoint the arrangement and the units comprising an activated-sludge plant are shown diagrammatically on the flow sheet, Figure 1. First there is a bar screen (1) for the removal of the large, coarse particles from the sewage followed by a settling tank (2) providing a com-

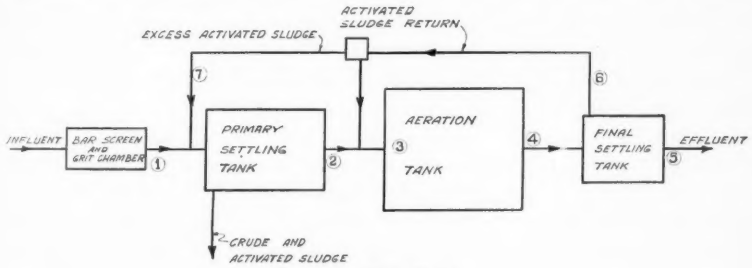

FIG. 1.—Flow Sheet.

paratively short period of detention for removing a portion of the larger suspended solids, thereby reducing the load upon the aeration tank; from which primary settling tank the sewage flows into the aeration tank (3) where it is mixed with previously activated sludge and then agitated and aerated for a period of from 6 to 8 hours; after which the resultant mixture of sewage and sludge flows to a final settling tank (4) where the floc is separated from the treated sewage by settling and the clear liquor is discharged from the plant (5) if the degree of treatment thus provided has

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been sufficient. The settled sludge is removed from the final settling tank and a part of it is returned to the aeration tank (6) where it is again brought into intimate contact with the sewage which is being aerated. The excess activated sludge (7) is generally returned to the influent end of the primary settling tank.

The name "activated sludge" is not one which correctly describes the process. A too literal interpretation of this definition might be taken as suggesting an association of the process with the solid matter or crude sludge of raw sewage, whereas no such relation exists. Originally, the definition was taken from the biologically active sludge. A better definition would be biological flocculation of the suspended and colloidal substances contained in the sewage. When sewage containing suspended and colloidal solids is agitated with air or other means, for a sufficient length of time, it assumes a flocculent appearance. Bacteria gather in these flocculi in immense numbers either by being strained out of the sewage or by growing in the flocculi, and the usual suspended particles grow by accretion of the material dispersed throughout the sewage. The action may also be defined as being one of oxidation, assuming that oxidation is a principal step in the purification of sewage.

Irrespective of whether or not the process is one of oxidation or flocculation, it is known that particles of activated sludge are composed almost entirely of active, growing, microscopic organisms ranging in varieties from true bacteria up through the giant bacteria and a variety of free and attached protozoa. These microörganisms take their food from the colloidal and dissolved matter and the salts in the sewage. They are aerobic in action, that is, they must have oxygen to continue their functioning which explains why the mixture of sludge and sewage must be agitated to maintain the sludge in suspension and in continuous contact with atmospheric or dissolved oxygen. In the natural purification which occurs in a stream, reaeration, or the absorption of oxygen from the atmosphere, plays an extremely important part. This absorption is proportional to the deficit in the saturation. De-oxygenation, or the rate of biochemical oxidation of the organic matter, is proportional to the remaining unoxidized substances. In a quiescent, unsaturated liquid, the surface film becomes rapidly saturated with oxygen and can dissolve no more until that which has already been passed into solution has been carried to deeper strata. Mechanical mixing of the liquid continuously breaks up the saturated surface film into small masses of liquids, which are brought into contact with less saturated masses with an intimacy and frequency depending on the degree of agitation.

In an aeration tank the air must saturate the sewage below the surface of contact; this oxygen must then diffuse to the activated-sludge particles and these in turn must reach the colloidal particles in order to bring about

flocculation and absorption. These results are accomplished by stirring or agitation of the sewage and sludge. This also maintains the sludge in suspension which is quite essential. If sludge is allowed to stand it soon begins to putrefy and re-disperse and the work done in building up is lost.

The length of stirring or agitation is dependent, among other things, on the strength of the sewage. A strong sewage having a high biochemical oxygen demand requires longer aeration than a weak sewage. This is further influenced by industrial wastes, the presence of which has a large bearing on the time of stirring or aeration. These are reasons why the transference of data and comparisons of operation between plants can only be made under identical conditions. In studying the operation of activated-sludge plants, colloidal chemistry is of great assistance in the interpretation of results. The large surfaces of the particles of activated sludge, and possibly other agencies not fully understood, accomplish almost complete coagulation of the colloidal matter. When the sludge is in its best condition it will remove practically all of the colloids from the sewage. When under-aerated, apparently not all of the colloids are removed. When over-aerated the sludge is more finely dispersed and put back into a colloidal condition in the effluent.

A review of definitions and the theory of activated sludge indicates that there is a comparative lack of fundamental research on the properties of the sludge, with regard to its functions in the process of purification. From a practical standpoint, we do not as yet have a reasonable or a complete theory to determine the maximum amount of sludge to be returned to the incoming sewage. The experience of plant operators indicates that the results of volumetric tests of sludge concentrations are too variable to serve as a basis of control of the aeration process. Studies are now being made by various investigators on the oxygen demand of the sludge particles, and upon de-oxygenation, reaeration, stage aeration, etc. Refinements in methods of control and economies in operating costs may follow as the result of more complete knowledge of the oxygen requirements of activated sludge.

Types of Agitators and Aerators for Aeration Tanks

Although the details of activated-sludge plants may show decided variations in design, it may be considered that there have been only two general types thus far developed, namely:

1. Aeration and agitation by compressed air.
2. Aeration and agitation by mechanical means.

There is now, however, a third method which is a combination of the two methods.

From almost the very inception of the activated-sludge process and its practical application some 15 years ago, almost every conceivable device

and arrangement has been studied or tried for the agitation and aeration of the sewage and sludge. In the earlier plants, compressed air was most frequently used for the purpose, since, when properly introduced into the liquid, it will both agitate and at the same time supply a part of the oxygen required for aeration. Diffusion of air in these plants was accomplished through the ridge-and-furrow type of tank bottom. (Figure 2.) This system gave very thorough aeration and agitation, but on account of the direct rise of the air bubbles it did not give a uniform motion to the sewage and the volume of air required was comparatively high. With the introduction of the so-called spiral-flow type (Figure 3), the ridge-and-furrow type has become more or less obsolete. In the spiral-flow type of aeration tanks,

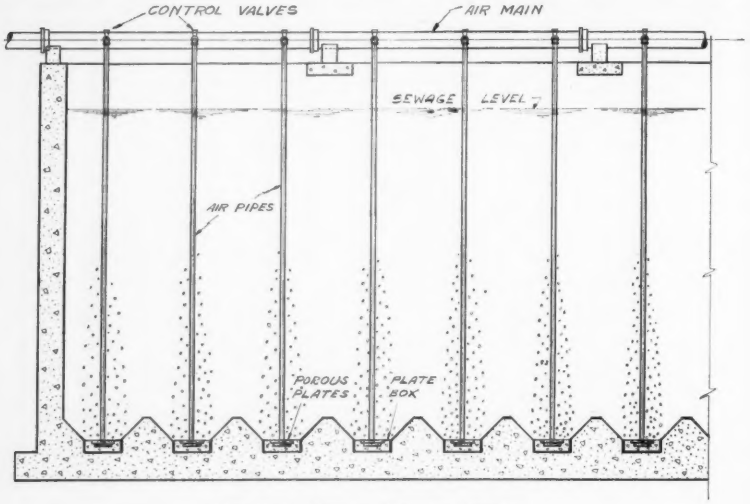

FIG. 2.—Ridge-and-Furrow Aerator.

the air diffusers are placed in the bottom at one side of the tank. When air is diffused through these plates, it imparts a transverse rotary motion to the sewage. This results in the sewage traveling in a spiral path from one end of the tank to the other. The uniform motion of the sewage makes it possible to keep the sludge in suspension with less air; this type is undoubtedly a decided improvement over the ridge-and-furrow type. The air supplied to the plates must be absolutely free from oil, dust or other impurities and must be delivered through pipes which will not rust; otherwise the plates will soon clog. The efficiency of the spiral-flow method of agitation depends upon the proper placing of the diffuser plates, the tank dimensions, the use of baffles and other variable factors. In both the ridge-and-furrow and the spiral-flow systems, the diffusers are placed in the bottoms

of the tanks, requiring air pressure slightly greater than that of the static head of sewage over the plates. Since these tanks are usually from 12 to 15 feet deep, the air pressure must be from 6 to 7 pounds, plus losses through the diffusers, piping, etc., being as a general rule between 8 and 10 pounds per square inch.

A more recent method of agitation is that of the so-called "air-lift channel" type (Figure 4), which consists of a channel 18 inches to 2 feet wide, placed at one side of the aeration tank. Air diffuser tubes are suspended in this channel at a point 3 to 4 feet below the level of the sewage. The lower end of the channel extends to within 18 to 24 inches of the tank bottom and the upper end is provided with a restricted opening or a throat so arranged that the mixture of sewage and air bubbles leaving this opening is

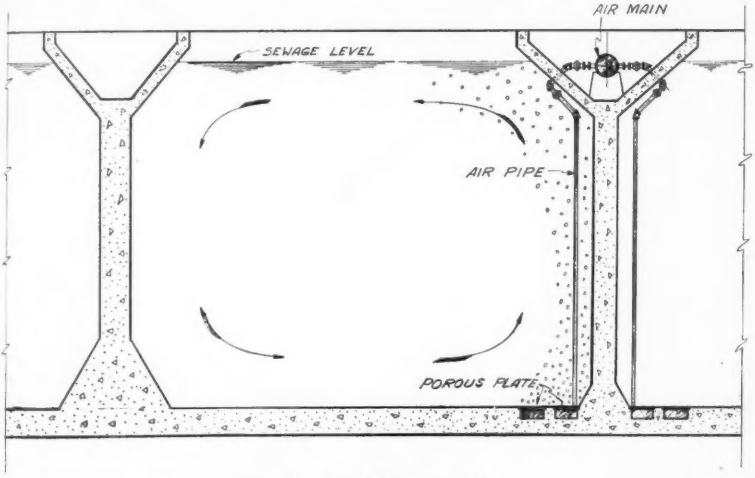

FIG. 3.—Spiral-Flow Aerator.

given a rapid horizontal surface velocity. The method is essentially of the spiral-flow type and must be provided with transverse baffles to prevent short circuiting. The volume of air supplied through the diffusers varies, of course, with the width and depth of the tank. For an average sized tank, the volume required to obtain non-settling velocities averages, I believe, 2 cubic feet per minute per lineal foot of tank. Greater volumes of air naturally give higher velocities, the higher velocities being required for stronger sewages. One apparent advantage of this system is the ease with which the tubes can be removed from the sewage for cleaning, without interfering with the operation of the tank. Another is the low pressure required for compressing air, averaging, I believe, 3 pounds total pressure per square inch as against 8 and 10 pounds for the types of aeration in which

the tubes are placed in the tank bottoms. Some of this gain in power is lost, however, by the increased volume of air required to operate this system.

Numerous devices have been developed for the mechanical aeration of sewage. As the use of compressed air diffused in small bubbles requires plates having fairly small openings, these diffusors are subject to clogging and increased air pressures. Early observations by various investigators had shown that a comparatively small portion of the air introduced into the sewage through porous plates was actually taken up by the liquor. The reason for this appears to be that air bubbles, in rising to the surface of sewage, carry with them a thin film of the sewage, and it is only this film which becomes saturated with the oxygen. It has been estimated that only between 7 and 10 per cent of the air blown through the sewage is actually

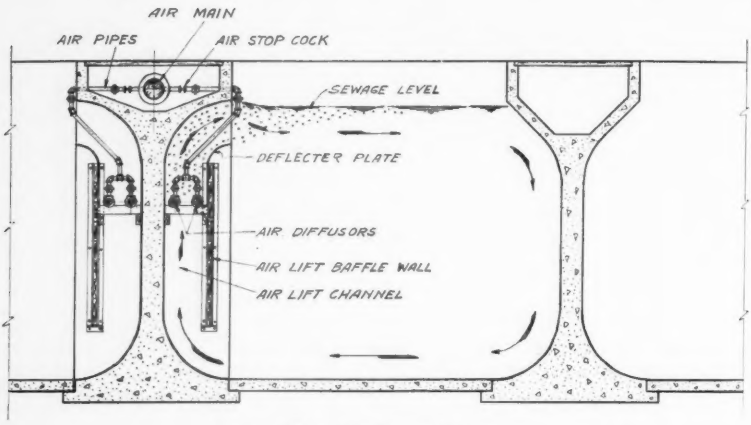

FIG 4.—"Air-Lift Channel" Aerator.

used for oxidation. The balance is used only for agitation. Many investigators concluded that mechanical agitation resulted in the continuous breaking up of such saturated films and the formation of new surfaces which, in turn, were quickly saturated by the air to be dissolved.

Mechanical agitators were then developed which were entirely independent of diffused air. Only a few of the methods have developed into extensive use. One of these devices is the Haworth paddle-wheel process as installed in the Sheffield plant in England. Neither it nor the Hartley spiral has come into use in this country. In his early experiments Haworth used a vertical cylinder equipped with a propeller which could be rotated rapidly to induce circulation. The flow through the cylinder was downward, with the return flow taking place in the tank outside. A similar machine but with an upward flow was developed at about the same time.

This machine is now known as the Simplex aerator. (Figure 5.) It consists of a stationary cylinder or uptake tube, at the top of which there is a revolving disk, fitted with vanes, designed to throw a thin sheet of sewage across the surface of the tank. As the sewage which is being sprayed strikes the surface of the liquid in the tank numerous air bubbles are formed and there is set up in the sewage a downward circular motion. There are a number of installations of Simplex aerators in this country. In fact the only activated-sludge plant in Pennsylvania, namely, the Willow Grove-Hatboro plant, is equipped with this type of aerating system.

A somewhat different type of mechanical aerator is that now being built by the Link-Belt Company. This produces practically the same flow

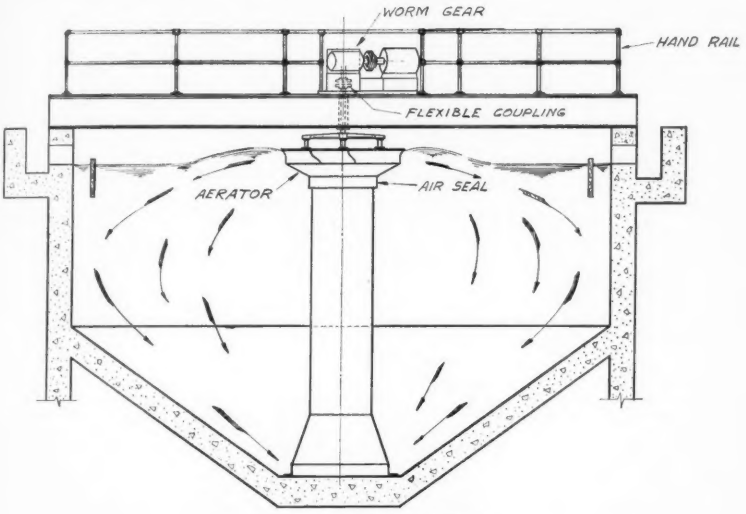

FIG. 5.—Simplex Aerator.

through the tank as that of an air-actuated spiral-flow type. (Figure 6.) With this method, agitation and circulation are produced by the action of a revolving, paddle-like element, located at one side and extending the full length of the tank. The blades of the paddle are in the form of narrow ribbons, carried on a shaft placed a few inches above the sewage level. A vertical baffle wall is placed parallel to and at a distance of about 18 inches from the wall of the tank. A metal apron curved to conform with the path of the paddles, extends from the baffle wall. Sewage is drawn into this apron and forced across the surface at a velocity of about $2^1/_2$ feet per second. The tank is provided with deflectors along the walls and transverse baffles to prevent short-circuiting. There are many other types of

mechanical aerators, such as sewage and air turbines, revolving brushes and others.

Another method of aeration is that which might be called mechanical

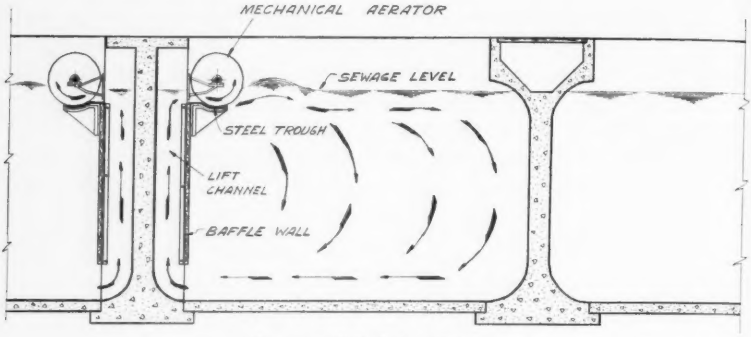

FIG. 6.—Link-Belt Aerator.

air. (Figure 7.) This method of aeration is one in which it has been attempted to combine the advantages of diffused air and mechanical agita-

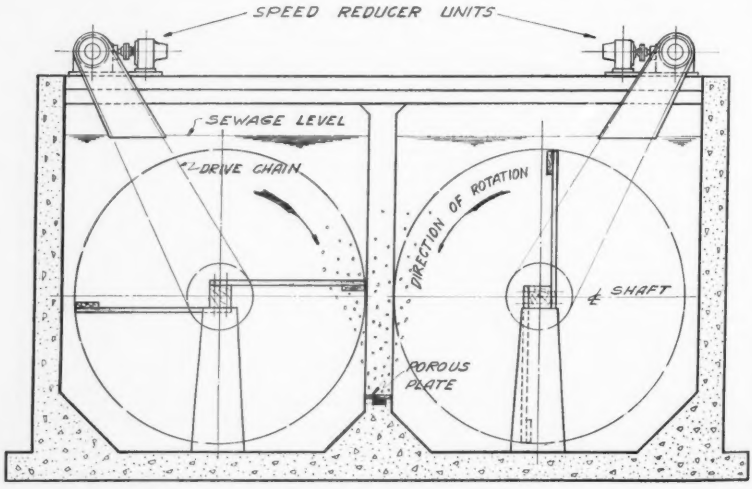

Fig. 7.—Dorrco Aerator.

tion and to eliminate the disadvantages of each. The system consists of a number of paddle-wheel units, attached at regular intervals to a horizontal shaft which passes through the aeration tank. Diffuser plates are set

in the top of an air channel located along the center line of the tank and elevated some distance above the tank bottom. When in operation the paddles are rotated downward against the stream of rising air bubbles. This provides a longer period of contact between the air and the sewage and distributes the air across the surface of the tank. The Dorr Company has an installation of this mechanical plus diffused air method of agitation and aerator, at Muskegon Heights, Michigan. The method has been investigated quite extensively at the Calumet Treatment Works. Mohlman's reports and published data indicate, however, that the same results can be obtained, with less power requirements, by introducing the air

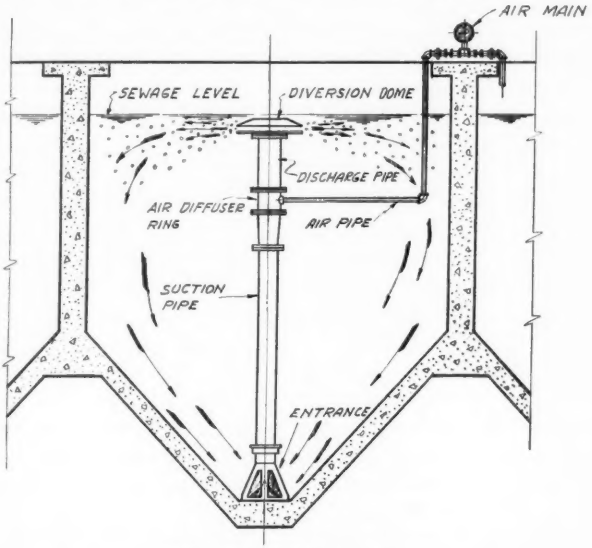

FIG. 8.—Air-Lift Aerator.

under the shaft and using the energy of the rising air bubbles to assist in turning the paddles. He states that the uniform circulatory motion induced by the paddle wheels is not broken up when the air is turned on, but, as would be expected, the air aids the circulatory motion of the liquor.

Another method of agitation and aeration, which seems to have considerable merit, particularly in the smaller plants, is that introduced by Kremer in Germany. (Figure 8.) This method consists of a series of air-lift units in one compartment, the number depending on the size of the plant. The air-lift unit extends from the bottom of the hopper to a point immediately below the surface of the sewage and consists of an entrance casting, suction pipe, air diffuser, discharge pipe and the distribution dome. This dome is

so designed that the mixture of air and sewage is discharged outward and downward so that in addition to agitation and circulation, there is also obtained an entrainment of the air bubbles. It is somewhat similar to the Simplex system of a rising tube and outward dispersion, except that the upward motion through the tube is effected by air rather than the revolving disk. Some of the advantages claimed for this method are the absence of moving parts, and its comparatively low cost of installation. The diffuser casting is placed about 3 feet below the level of the sewage, requiring, therefore, a low pressure air compressor or blower. Further, the air openings in the diffuser are large enough so that air filters are not necessary, as oil and dust will not clog the diffuser. Some advantage is claimed also because of the intensive admixture of the diffused air and sewage in the air-lift unit.

Design Features and General Data

Present day practice in the design of activated-sludge treatment plants usually calls for a primary settling tank used for the removal of the heavier suspended solids; an aeration tank used for the flocculation and oxidation of the remaining suspended and colloidal solids in the settled sewage; and a final settling tank in which the sludge is separated from the treated sewage. In a number of plants the excess activated sludge is returned to and mixed with the raw sewage entering the primary settling tank, from which it is removed with the raw sludge and generally disposed of by digestion and drying on underdrained sand beds.

First, if the sewage must be pumped, this pumping should be done in such a manner as to eliminate fluctuations in the rate of sewage application to the plant, as extreme fluctuations seriously affect the operation of the entire plant. This can, in smaller plants, be accomplished by variable speed pump units, automatically controlled through a float switch. For larger plants pumping more sewage, certain economies can be effected by using a combination of constant and variable speed pumps wherein the constant speed pumps carry the major portion of the pumping load and the variable speed or capacity pump takes care of the rates between the constant capacity units. In plants disposing of the sludge by digestion, a detritor or grit chamber should be provided to remove grit and sand present even in separate sewer systems. These can be of the longitudinal type, wherein the velocity is controlled by the flow area, but should be preferably of the mechanically operated type. Two types of mechanically operated detritors or grit chambers are available for the purpose. That furnished by the Dorr Company is based on area and the settling rate of the gritty particles. It is provided with a mechanism for the concentration of the settled material, which is then removed and washed by a grasshopper type of conveyor. The one furnished by the Link-Belt Company utilizes a

somewhat different principle. The sewage enters the grit chamber through an air-lift channel, extending the full length of the chamber. A spiral motion is transmitted to the sewage by the action of the diffused air and the velocity of this motion is controlled by the volume of air introduced. This is adjustable and is dependent upon the size of particles to be removed. Deposited grit is carried forward by the action of plows mounted on an endless chain and is finally deposited into an inclined screw conveyor, from which it is discharged into the receiving containers. This type of detritor is being installed at the Coatesville, Pa., activated-sludge plant, now under construction.

Primary settling tanks are generally designed so as to provide detention periods of 1 to $1^1/_2$ hours on the displacement basis, or about 700 gallons per square foot per day. These rates may be modified to meet the requirements of a strong or weak sewage. Most tanks are provided with equipment for the mechanical removal of sludge. This equipment can be obtained in various types, such as the scraper mechanism for square tanks supplied by the Dorr Company; the straight-line scrapers used in rectangular tanks as furnished by the Link-Belt Company; or the spiral scraper mechanism for circular-bottom tanks, now being furnished by the Hardinge Company. In the square and circular tanks, sludge is removed from the center of the tank, whereas with the chain-operated scrapers it is removed from a hopper at the influent end. Sludge should preferably be pumped out of the sludge compartment, as removing it at a low rate generally gives a denser sludge. Discharging excess activated sludge into the primary settling tank reduces the excessive moisture content of this sludge and does not materially increase the moisture content of the raw sludge. It is believed that the activated sludge assists in settling out solids in the raw sewage on account of the blanketing effect it exerts and its affinity for the smaller solids.

Aeration tanks are generally designed so as to provide detention periods of 6 to 8 hours. In determining the type of agitation and aeration to use, the designing engineer has quite a variety of methods from which to choose. It is generally conceded, however, that longer contact periods are required in the absence of diffused air. Such conflicting claims have been made with regard to power requirements of the various methods, that it requires a very careful study to determine on a comparable basis what each might require.

Final settling tanks for the separation of the sludge from the treated sewage seem to be quite varied in design and arrangement. English practice tends toward deep tanks with hopper bottoms, at the apex of which are placed the sludge outlet pipes. The sewage is carried to the center of the tank and dispersed under a baffle from which it flows across the tank to outlet weirs provided at the perimeter of the tank. In this country most

engineers provide some type of equipment for the mechanical removal of the settled sludge. Detention periods provided vary between $1^1/_2$ and 2 hours and surface rates between 800 and 1200 gallons per square foot per day. The settling of activated sludge is quite different from the settling of fresh sewage. The sludge admitted to the settling tank forms a blanket of almost equal depth all over the bottom. It does not build up on one side or one end as is the case with solids from raw sewage. Close observation of the settling characteristics of the sludge floc in glass cylinders indicates that the sludge precipitates in three stages. There is first observed the generally rapid coagulation or flocculation movement of the entire mass of solids. There is then observed the flocculation and relatively slow settling of the flocs which have become detached during the initial movement and last the gradual and slow settling of the finely divided floc. A study of these settling characteristics may disclose the reason why so many final settling tanks discharge light sludges with the effluents.

There are various types of equipment available for the concentration and removal of the settled sludge, similar in most respects to those used in primary settling tanks. In another type of tank, which can be designated as a radial-flow type, the sewage is introduced in the center of the tank, through a pipe carried up and terminating in a dispersion casting. The sewage flows under a baffle and across the surface of the tank at a continuously decreasing velocity. This principle is not new as it was used on some of the first Imhoff tanks built in this country. The decreasing rate of flow in this type of tank should meet the settling requirements of activated sludge, the bulk of the sludge being settled out almost immediately, the detached sludge then settling out, and the finely divided floc settling at the point of negligible tank velocity. Scraper mechanism for this type of tank can be so arranged as to set up little or no agitation in the sewage.

Contact tanks for sterilization, digestion tanks for the treatment of the sludge, sludge-drying beds, sludge-dewatering machines, are all incidental to an activated-sludge treatment plant, but although they are highly important adjuncts inasmuch as they have no direct bearing on activated-sludge practice, no reference will be made to them in this discussion except for brief comment. Once a balanced condition is set up in the activated-sludge tanks, the return of large quantities of overflow liquor from digestion tanks into the activated-sludge units may and in all probability will have disastrous results. This liquor, with its high B. O. D., should be returned at a very low rate or should be chemically treated prior to its return. Digestion tanks today are practically all of the high temperature type, operating between 80° and 90° F. They are equipped with mechanical agitators or stirrers to prevent the formation of scum and to circulate the tank contents.

Present Status of the Process

The activated-sludge process today is more an economic problem than a technical one. It is true that much research and experimental work should be done on the behavior of the sludge and its oxygen demands. Operating costs must be reduced and more positive control provided, particularly in the smaller plants. The activated-sludge process is more sensitive than sprinkling filters and requires much more careful and scientific control. The process is capable of removing from the sewage 90 per cent of the suspended matter and reducing its organic polluting matter, as represented by the biochemical oxygen demand, by 85 to 90 per cent. It reduces the bacteria contained in the raw sewage 90 to 95 per cent and when followed by chlorination is capable of delivering a sterile effluent which will not putrefy for several days.

Unfortunately, the individual plants while capable of performing these results have what might be termed their off-days. It is not unusual to visit an activated-sludge plant and find it delivering an effluent of inferior quality. Questioning will, as a rule, disclose the fact that carelessness on the part of some one caused an upset in the process, which will be remedied immediately. This may of course be done, but it is surprising to note how numerous these occurrences are, particularly in the smaller plants operating at or near their rated capacity. It is true that the supervision over these smaller plants is not as complete as it is in the larger plants. It may also be that the design of the plant does not provide sufficient flexibility to handle unusual conditions. All activated-sludge plants should be extremely flexible in operation. That is, they should be provided with means whereby, if necessary, the sludge can be reactivated, aeration tanks bypassed, final settling tanks bypassed, detention periods varied, means provided for the partial sterilization of the sewage or the activated sludge or both, as a preventive to bulking. In fact the more flexibility that is provided, the more assurance there is that operating troubles can be eliminated or quickly overcome.

Activated sludge for large projects requiring complete oxidation is well established. In large plants the flows, loadings, etc., are as a general rule not subject to the same degree of fluctuation encountered in the small plants. In the small plant it is also more difficult to secure the technical control so necessary for the proper operation of this process. Methods of sewage treatment giving results approaching that of activated sludge are now well developed. In fact there are numerous instances where, with ample dilution, the process of clarification, stabilization and sterilization of the sewage can be accomplished advantageously with chemical processes. This is particularly true for the smaller plants. Also the sludge problem encountered in the past with chemical treatment is now being solved by

concentrators and dewatering machines and the residue can be incinerated if so desired.

Conclusion

In activated-sludge treatment plants, large or small, there are so many interrelated factors, that conclusions should not be drawn from data of experimental or small-scale operation without a most careful study of all conditions. Data are always available, the only question is whether they are right or wrong. Experimental results are only relative. The air requirements depend on the peculiarities of the sewage and vary in the same plant with different amounts of industrial wastes and with seasonal changes. Detention periods and air requirements of aeration tanks vary with the method of aeration used, the arrangement of the tank and the nature of the sewage. Too small or incorrectly designed final settling tanks can cause the best activated-sludge system to fail. Non-technical supervision of operation is today one of the most troublesome factors involved in the operation of activated-sludge treatment plants. The need of highly skilled operators cannot be too highly stressed. An operator or supervisor combining knowledge of the process with a trend toward analytical and research work is the ideal type for this process of sewage treatment.

Discussion

WELLINGTON DONALDSON, of Fuller & McClintock, New York: I think Mr. Streander's paper gives a very complete and a very accurate picture of present practice. I want to say, also, that I have a very keen appreciation of some of the difficulties he has mentioned in connection with plants. There are one or two types of aeration I did not see pictured here, one of which is the perforated pipe type of aerator. Perforated pipes have been used before and discarded, but a recent installation employs a modification of this type. Another type of aerator which has not been mentioned, is the one which employs some form of pump to circulate the contents of the aeration tank. There are a few tanks of this kind in this country but this type needs considerable improvement and perhaps Mr. Streander is justified in not mentioning them.

One feature of the activated-sludge process which has not been stressed by Mr. Streander is the reaeration feature. It is quite true that the trend of practice has been away from reaeration. Early plants did have the reaeration feature incorporated. At a meeting of the New Jersey Association Mr. W. M. Veitch in his interesting paper on the London, Ontario, plant stated that the operation of his plant depended on long time reaeration. The advantage of it ought to be considered very carefully in some instances but not in all. If you consider the number of pounds of

solids represented by sludge in the aeration tank and the number of pounds represented in the reaeration tank, it comes to this sort of proposition that you have available or held in storage a substantial part of your reagent free from contact with industrial wastes. Reaeration in such instances may be very useful where part of your sludge that is not affected by strong sewage or industrial wastes is ready to throw into the tank when it is needed. I disagree with Mr. Streander on one point that degree of clarification is closely related to the condition of the sludge. I have not found that to be true. With very poor sludge you may have clarification as with the best of sludge. The trouble with poor sludge comes later on in the process as bulking in secondary settling tanks.

The matter of plate clogging does not seem to be as serious as at one time, when we remember the Houston experience where every plate had to be taken out and cleaned. In some other instances the plates have had to be cleaned but clogging does not seem to be as serious as anticipated.

I agree very thoroughly as to the need of research; we have many things to learn. Very little is known about the organisms which are essential to this process. Very strangely, we know more now about organisms such as *Sphaerotilus* which are detrimental. The present status of the process as applied to large plants, I think, will have to be admitted. We have been running plants a number of years and we know that this method is dependable for purifying sewage and that those plants which are manned by skilled persons are now showing a remarkably consistent operating record. The situation at the smaller plants, unfortunately, is not so good. A great number of these smaller plants have gotten into trouble through various causes. Without attempting to enumerate all of them, I can indicate some of them.

One cause has been the failure to recognize that in the smaller plants fluctuations of flow and character of sewage are often extremely high, whereas in the larger systems the fluctuations are more or less leveled out. Another reason, of course, for troubles in the smaller plants is the lack of the kind of supervision that the larger plants are able to maintain.

The cost of power in little plants is apt to be expensive for several reasons. The big problem, of course aside from cost, is the ever present problem of sludge disposal; when that is solved satisfactorily the process will be much more satisfactory for general use.

The digestion of solids has not always been so successful on account of the water content of the activated sludge and the time it has taken to decrease this water content. This has resulted, in a number of instances, in digestion having failed. Experiments have been made in handling sludge by filtering it to get it out of the way without the digestion stage. The Hagerstown, Md., plant, now building, provides for direct

disposal of sludge—combined activated sludge, primary sludge and screenings—without the digestion stage. In spite of the difficulties of smaller plants, I am optimistic in regard to the use of this method for such plants. By further developments and research work there will be brought into our hands greater simplicity of operation. I have no hopes that we can lock the plant up and permit the operator to go on a vacation. It is a big jump from the old type of plant to one of the activated-sludge type where we have much machinery to look after.

The Care and Operation of Chlorine Control Apparatus*

BY K. A. KEIRN

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The use of chlorine in sewage treatment is steadily increasing. The necessity for accurate measurement and dependable application at specific points is becoming more important. This leads us to the consideration of the functions of a chlorinator, which may be summed up as follows:

1. To control the removal of the chlorine gas from the container.
2. To measure accurately the rate at which the chlorine is being used.
3. To keep this rate of flow constant, regardless of variations in pressure of the gas in the container.
4. In the case of a solution-feed type apparatus, to mix the gas thoroughly with water so that it is completely absorbed, and

Lastly, to insure continuous uniform treatment of the sewage at the point applied.

In order that a chlorinator may perform its functions 100% it is necessary that *reasonable* attention be given the apparatus. As to the word "reasonable" Webster describes it as being equitable, moderate or fair. Where chlorine control apparatus is installed for any phase of sewage treatment an investment has been made that can be either a money saving investment, an economical health protecting measure, or a burdensome and costly item in the operating budget, depending on the way in which the operator cares for the chlorinator.

The plant operator should appreciate that the chlorinating apparatus is of considerable assistance to him in producing a satisfactory effluent without the necessity of using mixing vats, orifice boxes, etc., on which he would need to be constantly checking. He should consider it his duty to give such apparatus under his jurisdiction reasonable care.

The care of all types of chlorine control apparatus is practically the same, and the following suggestions may be modified for any of the various types, although they are suggested with the vacuum type chlorinator in mind. While there are no moving parts to be lubricated at specific intervals, there are a few operations which should be considered as routine.

Daily.—The apparatus should be tested at least once daily for chlorine leaks. No odor of chlorine should be noticeable around the apparatus and any leak should be stopped as soon as discovered. The loss of weight of chlorine containers should be recorded daily, thus giving a check on the

* *Round Table Discussion, Buffalo Meeting, New York State Sewage Works Association, June 11, 1932.*

operation of the apparatus. Chlorine residual tests made at the predetermined intervals indicate whether the rate of feed is being maintained in accordance with the demand of the sewage flow.

Weekly.—The glass parts should be removed and washed with warm water. It may be found desirable to use a washing compound such as Gold Dust on the inside of the bell jar. Hard rubber floats should be cleaned and special care taken that the seat is not distorted. When reassembled this valve should work freely and the needle be set that it cannot be completely removed from the seat. Keep all unpainted metal parts coated with a solution of vaseline in gasoline to prevent corrosion and deterioration. The screen on the water line should be examined and cleaned if necessary.

General.—Before containers are connected to the chlorinator, they should be taken outside the building and the valve opened about one-third turn for a minute or two. Although extensive precautions are taken to have the cylinder free from impurities, there may be foreign matter in it at times. These impurities usually rise to the top of the container and are often carried off with the first gas withdrawn.

When connections on lines conducting chlorine gas are broken, the open ends should be plugged immediately to prevent the entrance of moisture from the atmosphere, which would cause subsequent corrosion.

When cleaning chlorine pipe lines, rinse with alcohol or carbon tetrachloride and allow the liquid to evaporate to dryness before reassembling.

Graphite grease should be used on all hard rubber threads in order to facilitate disassembling the parts when necessary.

A plentiful supply of gaskets for all connections will insure tight joints without undue strain on the fittings. Use one new gasket to make up the joint—it is very seldom necessary to use more than one.

The platform scales with which the weight of the containers is checked should be kept in good condition.

The chlorinator should be kept clean. Cleanliness does not insure perfect operation but invariably the clean chlorinator gives the best service for the lowest cost.

So much for care. We will now take up the operation of the vacuum type chlorinator and will consider the principal parts of the apparatus, and the function of each.

The chlorine passes as a gas from the main tank valve through the auxiliary valve fastened onto the tank, through a flexible tube to the manifold at the side of the pedestal. From there it passes up through the chlorine reducing valve into the bell jar. From the bell jar it is drawn through the orifice on the chlorine meter into the adjustable head tube, through the chlorine chamber to the injector throat where it is absorbed in water, and the resultant solution of chlorine and water then passes through

solution tubing to the point at which it is introduced into the sewage to be treated. The water to operate the apparatus passes through a strainer, water pressure reducing valve, through hose to the injector where it picks up the chlorine, and thence to the point of application. Gauges are used on either side of the reducing valve to give the operator a knowledge of the actual operating pressures and a small tap from the water line in the tray supplies the tray valve.

The tank pressure gauge indicates at all times the pressure of chlorine as supplied the apparatus. This serves as an indicator as to when the container is empty, the pressure falling off rapidly when the container holds no more chlorine as a liquid.

The chlorine inlet tube serves the double purpose of conveying the chlorine into the apparatus, and as a support for the chlorine reducing valve assembly. This inlet tube is so arranged that it may raise or lower the reducing valve and float assembly controlling the water level inside the bell jar.

The chlorine reducing valve, operated by a ball float, is of fine construction and gives accurate control of incoming chlorine gas. Functioning with the other parts of the apparatus it maintains a constant flow of chlorine for any one setting of the apparatus, regardless of variations in the pressure of the chlorine supply.

The bell jar sets in the tray and houses the reducing valve, meter and air relief trap.

The meter tube consists of a glass tube with a calibrated orifice on top. The standard calibration is in pounds per 24 hours and the scale for reading the flow of gas is etched on the tube.

The chlorine chamber serves as a reservoir into which the chlorine drawn through the adjustable head tube is taken, and subsequently feeds it to the injector. The adjustable head tube is attached to the rack, the handle of which serves as a control handle. This raises and lowers the tube through the chamber to the desired setting on the meter tube.

The air relief trap is provided to admit air to the bell jar in case the chlorine supply is shut off and the water supply permitted to continue to flow through the injector. This trap also provides a means of escape from the bell jar of the chlorine gas which leaks through the reducing valve in case the water supply is shut off. This trap is connected with a special chlorine tubing which leads to a point outside the building and is installed in such a way as to avoid traps.

The tray serves as the assembly body of the apparatus to which the above mentioned parts are attached, and in addition contains a float operated water inlet valve for a fresh water supply to the tray outside the bell jar as desired for the purpose of sealing the bell jar and as a makeup supply to the head tube. The tray also has an overflow to care for any

excess water that may be admitted and as an aid for maintaining the water in the tray at a constant level even with the top of this overflow tube.

Probably the most important part of this type chlorinator is the chlorine injector. This is in two parts and is located in the center of the tray. Its function is to create the necessary operating vacuum and to film out the water passing through the throat so that the chlorine gas is readily absorbed into a solution for application at the desired point.

A few operating suggestions might be mentioned.

It is necessary to open the valve controlling the water supply to the apparatus and make certain that the water inside the bell jar and in the tray assume the proper levels before opening the gas supply. In stopping operation, the gas is turned off and the water permitted to flow until all gas is withdrawn from the bell jar.

By adjusting the reducing valve carriage the water level inside the bell jar corresponds with the zero calibration of the orifice meter tube. This also corresponds with the level of the top of the tray. The top of the adjustable head tube must be set opposite the figure on the meter tube indicating the desired flow of chlorine, and must have water rising to this height constantly. This height of water in the meter tube being the exact measure of the drop across the orifice on the top of the tube, and for each setting the scale indicates the amount of chlorine being measured in pounds per day.

Sufficient cylinders to supply not over forty to fifty pounds each per day should be connected to the apparatus.

Heating, housing, water pressures, points of application, etc., as well as applicability of various types of apparatus, can be discussed only in the light of local conditions.

Industrial Wastes and Stream Pollution

Stream Pollution and Self Purification*

By John W. M. Bunker

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Water is the world's best known solvent. Surface waters are, in reality, solutions. In these solutions there are materials in suspension, some floating and of such size as to be obvious to casual inspection, other suspended materials so fine as to impart a turbidity to the waters. Among the suspended materials are the macro- and microscopic forms of life both animal and plant. Nowhere in nature do we find chemically pure water. Such water would be undesirable for either man or aquatic life, since the dissolved gases and salts make the water more palatable for the former and the dissolved materials are the food for plants and small animals, which in turn are the food for fish.

Mr. F. H. Newell has catalogued the use of streams as follows:

1. Drinking water.
2. Accessory to food production (watering cattle, irrigating fields, supporting fish life).
3. Waste disposal.
4. Industrial uses.
5. Transportation.

and to this the Conservation Commission of New York adds

6. Recreation.

Pollution of streams is caused by the addition of waste materials in the form of sewage and/or industrial wastes. A polluted stream may be potentially dangerous as drinking water or it may be a nuisance to the senses. It may clear itself promptly of the objectionable conditions, or these may persist. It may be that excessive quantities of industrial wastes will so deplete the life of the stream that self-purification is hindered or prevented On the other hand it is surprising how much added material in a stream can be handled by natural forces of self-purification.

I shall omit the question of danger from pathogenic organisms, and consider only the pollution of an organic nature. The distinction between or-

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ganic and mineral matter is from one point of view, more apparent than real. Organic matter is that which is alive, was recently alive, or was produced by a living thing. But that which lives today, dies tomorrow. After death the corporeal structure inevitably disintegrates. Dead organic matter becomes mineralized. On the other hand, there is a distinction between organic matter and mineral matter that is more real than apparent. Organic matter has a high content of potential energy, as will be explained later, which is different from the rather low potential energy of mineral matter.

The structure of protoplasm itself depends upon a cunning biological synthesis of mineral ingredients composed of chemical elements. At the two extremes, then, we have living protoplasm and lifeless mineral matter. Each is unaffected by those changes which we group together under the heading of "decay." Protoplasm and mineral matter differ in respect to solubility. Protoplasm maintains its structural integrity in water, while mineral matter more or less dissolves. The protoplasm in a stream, therefore, will always be found in suspension or in the sediment, while the solution which is the stream itself will contain the dissolved mineralized material. But protoplasm on death under natural conditions loses its integrity. It decays. The loss of the quality of life weakens its resistance to solution. Hydrolytic cleavage starts the disintegration; microörganisms accelerate the further breakdown of the once living structure; the broken fragments become more and more soluble and they develop a strong chemical affinity for oxygen. If this biological oxygen demand be satisfied, the further changes in disintegrating organic matter become slower, the fragments decrease in chemical activity, and decay has given way to mineralization. What was formerly organic matter in suspension has become stable mineral matter in solution.

The mineral matter in solution in a stream becomes available as food for plants but it no longer will directly support animal life. Plants are the basic food of animals and therefore it is obvious that the same mineral material which today is in solution in the water, may tomorrow be taken up by a water plant, and the day after may be gobbled by a fish which sooner or later is likely to be caught by man.

The cycle of degradation of organic matter into mineralized material once having been completed, the contents of a stream give no cause of offense to the senses. Polluted water has been purified. If during the breakdown into reactive fragments the supply of oxygen be insufficient to satisfy the demand of these fragments, further chemical changes are of such a nature that gaseous products, offensive to the senses, are produced. The stream under such conditions may constitute a nuisance.

Streams that are used for disposal of human and industrial wastes become altered in both their organic and mineral content. Whether or not such

streams become offensive depends ultimately upon the ratio of oxygen supply to oxygen demand. The natural purification of streams, therefore, while it is affected by a great variety of factors, must depend ultimately on biological oxidation.

Let us review some of the factors which contribute to natural purification, dismissing from our consideration such obvious conditions as mechanical aeration of the water in turbulent and torrential streams. In the first place, why does the stream-bed not fill up with all the stuff that falls into it, leaves from trees, run-off from farm land, sewage from dwellings or sewerage systems? All these matters contain solids, many of which are not soluble when they enter the water. We might inquire equally as well why the earth does not become piled up with dead leaves, grass, plants and animals. The answer to both questions is one word "bacteria."

Organic matter is composed of protein, carbohydrate and fat along with mineral salts and water. The large proportion of water in living things is often overlooked. Conservatively speaking, three-quarters of protoplasm is water.

The first blob of primordial protoplasm must have been of the nature of plant life. Its only possible food supply consisted of mineral salts, and only plants can grow on a strictly mineral salt diet. A characteristic of animal feeding that some of the food must be of plant origin precludes the possibility of animal life having originated until after plant life was established. This dependence of animals upon plants is an important factor to keep in mind in a consideration of natural purification of streams. Plants, beside being of fundamental importance to animal life, are more versatile than animals in respect to their ability not only to feed on mineral matter, but also to extract foodstuffs and energy from dead animal material. It is this power of the microscopic plants which we call bacteria, to degrade various kinds of organic materials and in the process to abstract energy for their own life purposes which is responsible for the early stages of stream purification consisting of decay of organic pollution.

A life process of green plants which sometimes is not clearly understood is the power of these green plants to capture and bind energy from sunlight. In the presence of the green coloring matter, called chlorophyl, the leaf exposed to sunshine brings about a synthesis of carbon dioxide and water to form starch. Starch consists of carbon, hydrogen, oxygen and *energy*. From this synthetic process there is left over some molecular oxygen which is cast off as a by-product.

Under the water, but near its surface at depths to which sunlight can penetrate, this same process of photosynthesis is carried out by the green microscopic plant-plankton. The excess oxygen given off is absorbed in the water as dissolved oxygen. Water plants attached to the bottoms of shallow streams or near the shore line also play their part in oxygenation of

water. This photosynthesis is, however, the "busy-work" of the green plants; for the business of living, the same plants, big or little, must breathe, that is, oxygen must be diffused into their component cells and carbon dioxide is inevitably liberated. Fortunately, the liberation of oxygen on a sunny day from photosynthesis is far in excess of the requirements of oxygen for breathing purposes by the same plants. Thus, the plants set a splendid example to the rest of the world and justify their existence by giving more than they take.

In a stream, the presence of plant-plankton helps keep the water sweet. It may be the chief source of oxygenation of shallow, quiet waters, producing on warm, sunny days a super-saturation of dissolved oxygen. Naturally, the more turbidity there be in a body of water, the more photosynthesis will be restricted to the surface. And in any case, the action becomes less and less the deeper one goes below the surface, due to the absorption of light by the water itself. Photosynthesis in water is essentially a surface phenomenon, and the diffusion of oxygen from upper layers to lower layers is affected in the same way by temperature, currents, etc., whether the oxygen be absorbed from the air or produced by green plants.

If, then, our thesis be valid that the purification of a polluted stream is governed largely by the ratio of oxygen supply to oxygen demand in the waters, the rôle of both floating and littoral plant life in these water is obviously of paramount importance.

In respect to the plants which do not have chlorophyl, plants such as the colorless fungi and bacteria, it appears that their function is parallel to or identical with the function of the animal plankton. By feeding upon the organic matter already partly hydrolyzed, the bacteria and zooplankton abstract energy from that organic matter, pull it apart, absorb some of it and then discard the substance as waste material. During this phase of destruction of masses of organic matter we say that the material is undergoing decay. The bacterial and animal wastes are nearer to mineralization than they were when they existed in the condition of food for these small living things. The biological oxygen demand of these wastes is generally much less than that of the initial material from which they were produced.

For instance, Purdy, in his studies of the Illinois River, has observed that one tubifex worm with its head buried in the slimy mud at the river bottom and its posterior end waving free in the water above, seems to eat for at least 21 hours out of twenty-four. From one worm the fecal pellets which are discharged quite regularly in the course of a day, supposing that the animal stops eating for 6 hours, which is an over-generous allowance, if placed end to end would form a thread of worked over sediment 68 inches long, or 45 times the length of the animal itself. Because of the small diameter of each pellet, its total surface exposed to the water is very great, as compared to its mass. Each millimeter cubed of material has

26 square millimeters of surface. The biological oxygen demand of the slimy mud before ingestion by the worms is 6.7 p. p. m., while that of the fecal pellets is only 2.8 p. p. m.

Again, take the case of the Genesee River as studied by the late G. C. Whipple in 1912. Above the City of Rochester the dissolved oxygen in the Genesee in summer was 110% saturated. Just below the sewer outfall of the city, the dissolved oxygen was only 25% of saturation. At this point bacterial counts of 2,000,000 per cc. were obtained. In the course of two miles the bacteria had dropped to 400,000. Protozoa had increased from 100 per cc. to 2500 per cubic centimeter. Dissolved oxygen was reduced to 10% of saturation. In the next five miles the bacteria went down to 400 per cc., *B. coli* dropped from a peak of 1,000,000 to 10, protozoa were back to their normal level of less than 100, dissolved oxygen was up again to 35%, and the stream while not completely purified was certainly in a much better condition, thanks to the activity of its flora and fauna. Any stream so heavily polluted as was this one 20 years ago offers an admirable example of a cycle of conservation of matter in nature. In the summer of 1912 the deep gorge of the Genesee, below the City of Rochester, held between its rocky banks a stream of dun-colored puree. A light power launch running up the river did not turn up a glistening bow wave with the expected pleasing swish, the boat went "plowgh." Half a mile from the lake was the maximum zone of crustacean population, and from 800 per cc. the census rapidly fell to less than 100 per cc. at the river mouth. Each pleasant day one or more fishermen would be seen out on the stone jetties that guide the Genesee into Lake Ontario. Presumably fish were there to be caught. Crustacea and algae are favorite foods for fish. The fish when caught were carried to the Rochester frying pans—and ever the sewage from the city poured into the Genesee river.

By means of the microscope, changes among the microscopic organisms in water come to the eye of the observer. Minute herbivora, carnivora, and omnivora make up the changing population of surface waters, minor fluctuations take place as whole populations give way to new inhabitants, but a sudden persistent predominance of one kind, heretofore not numerous, is certain evidence that a change in the food supply has taken place. Usually this means that something has been added to the stream. If the new population is of the scavenger type usually associated with sewage—one may deduce that sewage pollution has taken place. He then proceeds to test the deduction by appropriate laboratory methods. As the pollution is mineralized and made clean, so also will the pollution type organisms give way to clean water organisms. One mile below the city, where the river widened into a shallow basin, the surface was broken by great bubbles breaking lazily as they do in simmering corn meal mush. Flecks of drab colored foam floated in large patches. The wooded gorge had all the

majesty of the Rhine but there was no pleasure-boating on its waters. The spectacle was one of scientific interest entirely devoid of any aesthetic quality.

In these waters under the microscope one saw all sorts and kinds of ciliate protozoa, bustling about with all the breakneck haste of a throng on the sidewalks of New York. In each case the observer wonders where every one is going, and in neither case is there any answer. Closer inspection showed that clusters of these protozoa were congregated here and there about a bit of semi-transparent zooglea or a fragment of decayed leaf, wherever there was spread a free lunch. No algae or living diatoms were found in these sewage impregnated waters; no larger forms of life. The visible things were detritus and ciliates. Only with higher magnification could one see the Brownian motion of the bacteria.

From lower down the river, samples disclosed the more ponderously moving rotifiers, busy for the most part in a majestic sort of way, inching along under the cover glass, reaching out their whorls of cilia, weaving back and forth in leisurely tempo, *as if* searching out choice morsels. All sorts of minute particles caught in the vortices of the cilial whorls spun and shot down toward the rotiferan maw.

I have seen tiny ciliates and diatoms engulfed by rotifers. Kofoid reports that ciliates prey upon bacteria. Thus some of the original organic matter of the sewage pollution has been transferred successively to bacteria, to protozoa, to rotifiers.

Meanwhile the number of green algae had begun to increase and the dissolved oxygen content of the water was no longer dropping. As the algae further increased the oxygen content of the water also increased.

In the cleaner water, aldermanic crustaceans appeared. What they eat I have never seen with my own eyes. Under the illumination of the microscope they become agitated and scuttle to the welcoming shade out of the field of view, much as politicians shun the white light of unwanted publicity.

Earlier biological surveys of streams endeavored to set up index organisms of clean or polluted waters by selecting from the types of floating plankton. Later studies support the conclusion that the life in the bottom sediment offers a better index of the condition of the stream. For instance, the bottom sediment at a given point may yield chiefly worms that tolerate a minimum amount of oxygen while at another point the predominating forms are insect larvae that breathe with gills like a fish, or snails which are typical of clean water. This gives a presumption that at the former point, organic matter was undergoing decomposition thus using up the available oxygen, while at the latter point the cycle of purification had been carried further and the biological demand of decaying matter was therefore not so great.

The significance of the bottom-sediment fauna was pointed out by Weston and Turner in their studies of the Coweeset River published in 1917. Further interpretations of the life in the bottom sediment have been elaborated by Richardson in 1928 after twenty years of study of the Illinois River. Between 1913 and 1920, clean water conditions on the Illinois receded down-stream at the rate of eight miles per year. As pollutional conditions spread down-stream, the number of tubificid worms at Peoria Lake increased from 16 per square yard in 1915 to 2400 per square yard in 1920. The floods of 1924 carried decomposing matter still further down stream and enormously increased the numbers of tubifex worms in the bottom sediment.

In the clean water areas still lower down, snails predominate on the bottom ooze. In the pollution areas above, a small bivalve mollusc predominates. In the snail zone, the fishing for carp and catfish has become poor because the fish cannot negotiate the large snails, while in the mollusc zone, the catfish are plentiful, feeding upon the bivalves, but the pollutional conditions are attended with so much production of nauseating gases that the flesh of the fish is too strong too eat.

At the present time it is difficult to name the index organisms which in a stream can be relied upon to show the sanitary condition of its waters. Ciliate protozoa suggest decomposing organic matter; rotifers are associated with cleaner water but they are found where leaves and harmless vegetation are decomposing somewhat; the green algae definitely prefer clean water rich in mineral constituents and ammonium salts. Plants attached to the shore or river bottom and living near the surface play a two-fold part in the stream life; while alive they absorb much mineral matter and engage in photosynthesis; when dead, their large mass through decomposition adds materials to the solution of the stream which support the life of plankton. Thus streams with a vigorous subsurface littoral growth are likely to have a large population of suspended plankton. The bottom life in polluted areas shows a limited variety of forms: in clear water without sediment, many varieties are in competition with each other.

While in this brief résumé no reference has been made to the fate of sewage bacteria of the pathogenic types, it is to be realized that their numbers are reduced with even greater rapidity than are those of the ordinary proteolytic sewage bacteria. As we well know, polluted streams will purify themselves if the load placed upon nature's scavengers is not too great, and if chemical wastes do not interfere with the natural flora and fauna of the stream. Whether or not these plant and animal forms in association can accomplish the necessary purifying action will be governed by the ratio of available oxygen in the waters to the biological oxygen demand of the pollutional material.

Required Degree of Treatment of Sewage Prior to Its Disposal by Dilution

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Translated by GORDON M. FAIR

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The degree to which sewage must be treated before it is discharged into a river depends upon local, seasonal and other conditions. Rivers can rid themselves of sewage matters by decomposition or by scouring. In most cases both processes are active in self-purification. Biological decomposition is particularly important. A river contains many different living organisms, large ones and microscopically small ones, animals and plants. By integration of all the processes of nutrition of these organisms, organic waste matters are converted into substances similar in character to those present in naturally clean rivers. In comparison with these processes of self-purification, mechanical movement of the water is more in the nature of an auxiliary process. The water is mixed thoroughly, sewage matters are distributed over a wider area, and the residue is scoured away by freshets. The effect of all these processes upon the sewage introduced depends fore nost upon the time of flow. Full, original cleanness is reached in about seven days of flow.

In connection with the processes of self-purification it will serve our purpose to distinguish between dissolved and settleable solids in sewage, counting as dissolved substances whatever solids are not settleable. The boundary between the two is not sharp and can shift widely in a short time as a result of physical, chemical and biological changes in the river. Generally, rivers attempt to convert the dissolved putrescible substances as soon as possible into settleable solids and to deposit them in some quiet spot. There they can digest undisturbed and are scoured away on occasion by flood flows. Sludge deposits such as these may be found not only in almost quiescent waters but also at relatively high mean velocities (such as 0.7 to 1.0 ft. per sec.) provided only that the river stretch is sufficiently long and uniform to afford the time necessary for sedimentation. The occurrence of sludge deposits, therefore, must be reckoned with in every river that is a sewage carrier.

The dissolved putrescible matter must be decomposed by aerobic organisms in order that damage or nuisances may not result. Hence sufficient oxygen must be continually present in the water. Pure oxygen-saturated brook water contains at temperatures of

40°	50°	60°	70°	80° F.
13.0	11.3	10.0	9.0	8.1 p. p. m. of oxygen

When a river receives a charge of sewage the oxygen content drops. The permissible limit in fresh waters lies at 5 p. p. m. (or about 50 per cent oxygen saturation) for trout, and at 2.5 p. p. m. (or about 25 per cent saturation) for other fish. If the water is not saturated, it will replenish its supply the faster the greater the oxygen deficit, measured in terms of percentage saturation. The oxygen content of river water is renewed by aeration at the water surface, by oxygen given off by green aquatic plants, and by the inflow of clean, oxygen-saturated water from tributary streams. With exception of the third factor, which cannot be generalized, the oxygen

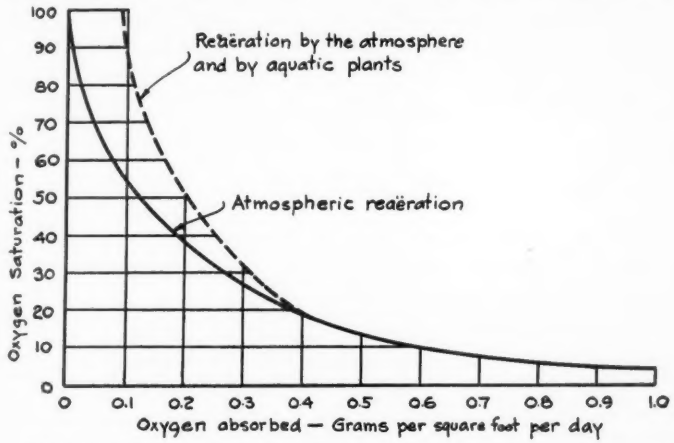

FIG. 1.—Oxygen Absorbed by Water of Different Degrees of Oxygen Saturation When Exposed to the Atmosphere or to the Oxygen Produced by Aquatic Plants.

intake (reoxygenation or reaeration) of a watercourse depends upon the extent of its water surface. Besides this, a great influence is exerted by the depth of water and the movement of the individual water particles relative to one another as well as by the wind which ripples the surface. From Figure 1 may be taken how many grams of oxygen a fairly quiet water will absorb from the atmosphere per square foot of surface in a day (full line). To this value must be added the oxygen given off by aquatic plants (dotted line). In the course of the daylight hours the latter amounts up to 0.1 gram per sq. ft. per day. This value is independent of the degree of saturation; hence it can even bring about "supersaturation."

From the distribution of dissolved sewage matter in a river (for example during a time of flow of one day) the permissible pollutional load of the

river can be calculated and the requisite performance of the clarifying works accordingly specified.

Example 1. A city of 100,000 inhabitants and a daily sewage flow of 100 gal. per capita lies on a small river whose width at flow line is 150 ft. and whose velocity of flow is 1 ft. per sec. Will the river remain unimpaired while destroying the dissolved sewage matters?

The 5-day biochemical oxygen demands of the dissolved and non-settleable solids are, respectively, 60 and 140 p. p. m. or $60 + 140 = 200$ p. p. m. $= \frac{200 \times 100 \times 3.79}{1000}$ $= 76$ grams per capita daily. During the first day about 30 per cent of the 5-day demand, equal to 23 grams per capita or altogether $23 \times 100{,}000 = 2{,}300{,}000$ grams of oxygen, must be provided. In one day the river water spreads over an area of $150 \times 1 \times 24 \times 3600 = 12{,}960{,}000$ sq. ft. The oxygen load due to dissolved substances, therefore, is $2{,}300{,}000 \div 12{,}960{,}000 = 0.177$ gram per sq. ft. per day. According to Figure 1 this load is permissible because it corresponds to the rate of reaeration at 60 per cent oxygen saturation and, if reaeration by aquatic plants is neglected, still to that at 40 per cent saturation. This is above the boundary line drawn for fish life, even if the river does not bring with it a higher oxygen content from its upland reaches. It is assumed in this connection that the river has overcome the effects of sewage introduced above; on the other hand, however, that the oxygen supply of the water brought down the river is not drawn upon to an appreciable extent.

It is possible to compute in the same way from the surface area and from other characteristics of an impounding reservoir how much sewage it can safely handle.

Example 2. A shallow impounding reservoir with a surface area of 35,000,000 sq. ft. has been built into a river heavily polluted with sewage. The sewage sludge is kept out of the stream by good settling basins. The sewage of how many people can be biologically purified in the reservoir?

The 5-day biochemical oxygen demand of the dissolved and non-settleable solids in the sewage is 76 grams per capita daily (from Example 1). According to the dotted line of Figure 1, the oxygen absorbed at the surface under conditions of heavy sewage pollution—for example, at 50 per cent oxygen saturation—is 0.22 gram per sq. ft. per day. The reservoir then purifies the sewage from $\frac{35{,}000{,}000 \times 0.22}{76} = 101{,}000$ people, provided the time of passage through the reservoir is 5 days. If the detention period is only 1 day, then only partial purification becomes possible. The oxygen demand during the first day being 30 per cent of the 5-day demand, the reservoir can then purify partially the sewage from $101{,}000 \div 0.3 = 340{,}000$ people.

The permissible load of settleable sewage solids which can be placed upon a water course cannot be determined in this way. Larger suspended solids, and in particular sludge which has accumulated on the river bottom, are decomposed by anaerobic organisms. The resulting products of metabolism are then worked over further by aerobic organisms. In order that there be no interference with this joint labor, there may be introduced into a stream, according to Mahr, in settleable form only about

$^2/_3$ of the quantity of organic matter that the stream must already handle in dissolved form. This gives us a measure also of the permissible load of settleable solids. When settleable solids are introduced it becomes necessary to determine whether the river becomes overburdened below the sewage outfall. In this connection it may be assumed that in a moderately swift river the bulk of sludge-forming solids settles out in the first two hours of flow.

Example 3. Let us look into the influence of the settleable solids in Example 1 According to Mahr it is permissible to deposit upon the river bed a layer of sludge which in the course of 100 days reaches a depth of 0.8 in. For the area covered by the river in two hours of flow, this amounts to $150 \times 1 \times 2 \times 3600 \times 0.8 \times {}^1/_{12} = 72{,}000$ cu. ft. of sludge. The quantity of sewage discharged during the 100 days is $100{,}000 \times 100 \times 100 = 1$ billion gallons. The allowable sludge content of the settled sewage, measured after two hours' settling in an Imhoff cone, therefore, is $\frac{72{,}000 \times 7.48}{1{,}000{,}000{,}000} \times 1000 =$ 0.5 cc. per liter. This degree of clarification can be reached by a detention period of $1^1/_2$ hours in a settling basin, provided that the water entering the river from storm-water outlets is subjected to sedimentation.

The biological activities connected with the self-purification of a river depend greatly upon temperature. During cold weather the oxygen content of the water is higher, the power of reaeration, on the other hand, lower than during warm weather. Biological activity, too, falls off at lower temperatures. If it is merely our purpose to carry away the sewage matters without resulting damage as far as the next large river, it is possible to increase the burden placed upon the river in winter. If, however, the pollutional matters must be broken down in a given river stretch (because of water-works lower down-stream, for example), better treatment is required in winter than in summer.

With rising temperatures, microscopic life becomes more active; along with it the stretch within which the river can handle a definite amount of pollution becomes steadily shorter. Since biological activity arises more rapidly than reaeration, the pollutional load must generally be reduced in summer in order that with decomposition concentrated within a shorter river stretch the dissolved oxygen may not disappear entirely and a nuisance result.

The rise in biological activity in summer can become particularly dangerous when old, undecomposed sludge lies upon the river bed. Gas production can then suddenly become so active that the gas bubbles are no longer taken into solution as they are formed but carry up with them to the water surface large masses of putrescent sludge. The resulting floating sludge masses are unsightly, absorb oxygen voraciously from the water and thereby menace still more the heavily stressed oxygen balance. The rising of sludge masses must be feared in otherwise healthy streams

as soon as the water temperature mounts above about 70° F. Care must be taken, therefore, to prevent the volume of gas per unit area from exceeding a certain value at higher temperatures in spite of greater activity. Since the amount of gas given off by a unit weight of organic material during a certain time at 77° F. (25° C.) relative to that at 68° F. (20° C.) is greater in the ratio of 693 to 485 (Figure 2), the permissible depth of sludge at 77° F. (25° C.) must be correspondingly less. In order to make sure of securing this condition during the hot season of the year, the sludge volumes introduced into the stream must be reduced, and this must be done several months in advance of hot weather.

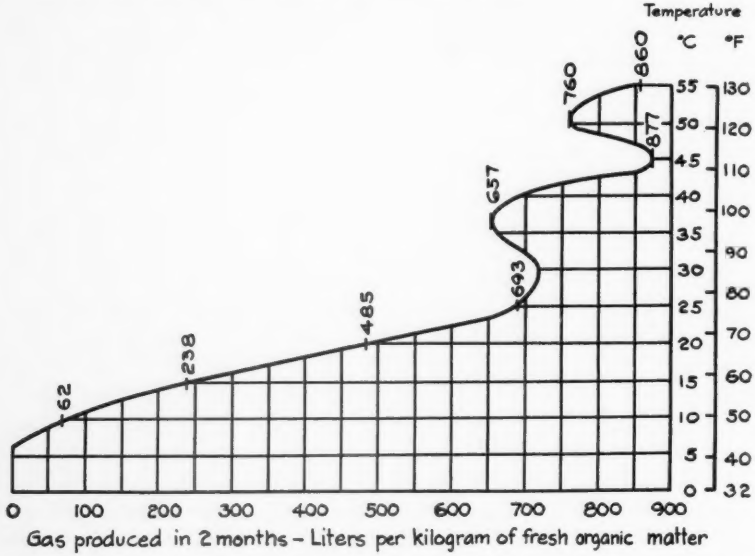

FIG. 2.—Amount of Gas Produced During Two Months by Sewage Sludge Held at Different Temperatures of Digestion.
(Data by F. Sierp)

Example 4. Let us investigate the influence of summer temperatures for the case studied in Examples 1 and 3.

The permissible residue in the Imhoff cone at 68° F. amounted to 0.5 cc. per liter. At 77° F. the amount may, therefore, be $\frac{0.5 \times 485}{693} = 0.35$ cc. per liter. It is not easy to keep within this value under average conditions in the case of purely domestic sewage. Should more unfavorable values be encountered distribution of the sewage among several outfalls sufficiently distant from one another should be considered first, and finally partial biological treatment.

According to the information available upon the subject, sludge places

a much greater burden upon a river than does an equal amount of dissolved organic matter. Hence it is particularly important to construct good sedimentation works, as well as storm-water tanks, and to operate them carefully.

Dissolved, putrescible solids are readily decomposed by the river provided only that it is given sufficient time to do so. For this reason impounding works which increase the time of flow of a river are advantageous if damage due to sludge banks can be avoided. For the same reason biological treatment processes which also handle dissolved substances in sewage are by far not so important in maintaining the cleanliness of a stream as are good sedimentation basins. If sedimentation works are to be enlarged because they are not adequate, they should be equipped with storm-water tanks before it is decided to provide supplementary biological treatment, such as trickling filters or activated-sludge tanks.

It is worth noting that the concept of "dilution" of the sewage in the river water does not occur in these computations. This is understandable in connection with settleable solids, because it makes little difference to the sludge lying on the river bottom what volume of water overruns it. For dissolved substances also, however, dilution constitutes but a single occurrence and is generally of less significance than the continued maintenance of the oxygen equilibrium, which is best expressed in terms of water-surface area.

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Editorial

The B. O. D. Determination

It is gratifying to publish in this issue the joint committee report on the procedure for determination of the biochemical oxygen demand of sewage, polluted water or industrial wastes. Probably only those intimately associated with the development of this recommended technique fully appreciate the long and arduous researches, conferences and discussions that have resulted in the preparation of the report. The great value of the B. O. D. determination has been recognized for many years, but its use was restricted in the United States until the past 15 years because of the unsatisfactory technique and the difficulty in obtaining check results in various dilutions. This difficulty has now been largely eliminated by adoption of the technique recommended in the joint committee report.

The history of the improvement in B. O. D. technique is interesting. For a detailed statement the reader is referred to Theriault's comprehensive monograph, "The Oxygen Demand of Polluted Waters," published in 1927 by the U. S. Public Health Service. For those who have followed the development of the method a number of landmarks stand out during the past 20 years.

The German and English work of Spitta and Adeney antedated American studies of biochemical oxygen absorption, but in 1911 Hoover was using a one-day 37° C. test at the Columbus sewage treatment works and in 1913 the same procedure was adopted at Baltimore. Phelps had become interested in the determination some years earlier and used it in the work at the Brooklyn testing station, as discussed in the noteworthy report of Black and Phelps on the pollution of New York Harbor, issued in 1911. In 1913 and 1914 a committee of the American Public Health Association made studies of the biochemical oxygen consumption of various sewages. A disappointing lack of agreement was found in different dilutions, and the discordant results rather dampened the enthusiasm of American sewage chemists for the method for the next five years, until Theriault explained the fundamental difficulty, namely, use of unsatisfactory dilution water. Meanwhile Lederer had developed and used the nitrate method at Chicago and Pearse laid the groundwork for the use of the B. O. D. per capita factor which has proved so useful in studies of industrial wastes.

Theriault's work, with Hommon, reported in U. S. P. H. S. Bulletin 97, issued in 1918, was the turning point in the successful development of the dilution method. He showed that if a dilution water had an appreciable

demand, a higher B. O. D. would be reported for higher dilutions, but that by using a series of dilutions and substracting one from the next higher, check results could be obtained.

The increasing number of sewage treatment works and more widespread appreciation among the public health engineers of the value of the B. O. D. determination greatly stimulated its use in the decade following Theriault's work. Further difficulties were encountered with dilution water from various sources, so that many laboratories used distilled water. This was found to give low results in work done in laboratories of the Sanitary District of Chicago, later confirmed in various other laboratories. In order to obtain a uniform, reproducible water, sodium bicarbonate was added to distilled water. This was found to be considerably more satisfactory than distilled or tap water. Likewise Theriault used distilled water buffered with potassium dihydrogen phosphate and sodium hydroxide. Further studies were made in a number of laboratories including those under the direction of Buswell, Hatfield, Mohlman, Rudolfs, Theriault, Warrick and others, of various synthetic dilution waters of more or less complex composition, but in general these were not found to be necessary if the pH value were held within reasonable limits by bicarbonate or phosphate buffers. The dilution water recommended by the joint committee contains 300 p. p. m. sodium bicarbonate. This water need not be stored, but should preferably be used soon after the bicarbonate is added. If stored for a week or longer the bottle should be tightly stoppered. The water should be aerated before the bicarbonate is added.

In England the use of the B. O. D. test at sewage works is increasing. The test was originally developed for effluents in England, with the Royal Commission standard specifying that a biologically treated effluent should not absorb more than 20 p. p. m. dissolved oxygen in 5 days at 18.3° C. Until recent years, however, the test was not used on raw or settled sewage, and it is still not used widely in England, as it is in the United States, for measuring the efficiency of sewage treatment.

In Germany the analytical difficulties of the B. O. D. test have led Dr. Sierp to develop his direct method for oxygen absorption, which has been favorably received in the United States for special work on sludges.

There are still frequent complaints about the lack of agreement in various dilutions of the B. O. D. test, but a careful study of the results will indicate that the discrepancies are usually due to sampling errors, errors in technique, or the presence of germicidal substances in the sample. Notwithstanding these difficulties the dilution method is now the chosen method for the B. O. D. determination in practically all American laboratories, and will continue to be improved and standardized. For this reason the standard technique recommended by the authoritative joint committee deserves careful study by all readers of THIS JOURNAL.

Book Review

Taschenbuch der Stadtentwasserung. By KARL IMHOFF, Chief Engineer, Ruhrverband, Essen, Germany. Sixth edition. Cloth. $4^1/_2 \times 7^1/_4$ in.; pp. 152; numerous charts and line drawings. Published by R. Oldenbourg, Munich and Berlin.

Lord Kelvin tells us "when you can measure what you are speaking about and express it in numbers you know something about it, but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind." The progress of engineering is truly in accordance with this statement, for its history is one of measurement and numerical definition. Lagging behind most branches of engineering in this respect has been in particular that branch which deals with sewerage and sewage disposal. As the years pass, however, there come to light more and more numerical measurements that give this field its much needed arithmetic background. Conspicuous among those who have seen and tried to meet this need as simply and directly as possible has been Dr. Imhoff, who from time to time has seen fit to boil down his rich and varied experience in slender but up-to-date books of which the "Taschenbuch" is the most widely known and read.

The sixth edition of this book, like its predecessors, lays no claim to being a treatise upon sewerage and sewage disposal. Its purpose remains to provide the tools for the solution of the arithmetic problems encountered by the engineer, and to provide them in such a way as to avoid time-consuming computations that are not warranted at the present stage of the game.

There are four main parts to the book. The first section deals with the principles of sewerage, summarizing in staccato style the things the designing engineer should keep in mind. The second section gives the computations entering into the design of the sewerage system (covering both sanitary and stormwater flow) and includes 17 useful hydrologic and hydraulic diagrams. The third section deals with the structural problems involved in the design of sewers of small and large cross-section. These three sections occupy about one-third of the book; the fourth, which has assumed increasing proportions in the present edition, deals with computations pertaining to sewage treatment and disposal. In this section as well as in the preceding ones the author tries to provide no more than the essential and necessary information and to define the elements of design in numerical terms. That as a result he may appear to be a bit dogmatic at times constitutes both the weakness and the strength of his presenta-

tion. The sequence of subject-matter of the fourth section is as follows: sewage analysis, disposal of sewage in water, screens and racks, skimming tanks, grit chambers, settling tanks, sludge treatment, chemical treatment processes, biological treatment processes, miscellaneous treatment problems and sample computations for four different types of plants. A table of English and American units and an index complete the book.

GORDON M. FAIR

Reviews and Abstracts

H. W. STREETER

The Bio-Chemical, Bio-Physical and Physical Principles Underlying the Self-Purification of Crude Sewage Liquor

By W. E. Adeney

The Surveyor, **82**, 91–94 (July 29, 1932)

The author discusses the advances which have been made in our knowledge of the scientific principles underlying the newer methods of sewage treatment and of their bearing upon the subject of the self-purification of normal crude sewage liquors. The satisfactory disposal of such liquors depends first upon the completeness of separation of organic solids, both suspended and colloidal, from the impurities in true solution and then upon the efficiency of self-purification of these two classes of polluting materials. These steps are:

1. Coarse suspended solids removal by plain sedimentation.
2. Fine suspended solids and colloids removal by the activated-sludge process.
3. Biochemical purification of the above solids by anaerobic digestion.
4. Biochemical aerobic purification of dissolved organic material in the activated-sludge tank effluent either on sprinkling filters or by adequate dilution in oxygen-containing streams.

Biochemical Changes in Sewage Matters Under Aerobic and Anaerobic Conditions.—From studies of the interrelationship of bacterial activity and dissolved gases (oxygen) in polluted waters, it has been possible to trace the chemical changes which occur during the process of natural purification of polluting substances in colloidal or soluble form. Thus in the presence of dissolved oxygen two distinct and progressive stages of bacterial fermentation proceed according to a definite law: "The quantities of oxygen consumed and of products formed, on the completion of each stage of aerobic fermentation, are constant for similar volumes of the same polluted water." The strength of sewage as determined by the oxygen demand test is based upon this law. The first stage of the process (known to us as the carbonaceous stage) produces mostly carbon dioxide, ammonia and water; in the second stage (the nitrogenous stage) the ammonia and humus present are oxidized to nitrates and carbonates.

Putrefactive products are formed only during the first stage when dissolved oxygen is exhausted and never occur in the second stage of fermentation. This latter stage ceases entirely under such conditions of oxygen exhaustion. During fermentation under anaerobic conditions in the presence of nitrates, these nitrates are reduced in preference to organic oxygen compounds. No offensive products of biochemical reduction are formed by this procedure and the organic impurities undergo first stage fermentation just as under aerobic conditions. However, energy is required to make available the oxygen from nitrates, thereby resulting in a slower fermentation reaction than when free dissolved oxygen is available.

The solid organic impurities after separation from the crude sewage liquor also undergo similar fermentative changes, when mixed with reducible oxygen compounds such as hydrated peroxide of manganese. The anaerobic sludge digestion process as practised at Birmingham is an exemplification of this principle where the fermenting sludge is inoculated into the fresh sludge from the sedimentation tanks and nuisance from offensive odors is avoided. Such nuisance prevention may be due to the presence of the humus by-products in the fermented sludge with which the fresh sludge is mixed.

The Bio-Physical Principles of the Self-Purification of Crude Sewage Liquors.—In addition to the biochemical oxidation processes which the bacteria bring about, they may also cause a rapid flocculation of the colloidal organic impurities because of the electro-negative charge which these organisms carry and which would tend to combine with the positively charged colloidal particles. A precipitation of colloids would thus occur in combination with the finely divided suspended impurities before either class has been appreciably affected by the biochemical processes of oxidation by the same bacteria. This is, in fact, the principle employed at Birmingham where the sedimented liquors are aerated for one hour before treatment on the filters. The organic colloids are thus precipitated and the effluent passed to the filters at twice the normal rate of flow.

The Rate and Mechanism of Aeration of Sewage Liquors in the Activated-Sludge Process.—Because the action of saprophytic bacteria in the activated-sludge process is dependent upon the supply of dissolved oxygen, the rate at which this oxygen can be introduced into and mixed with the sewage liquor is a controlling factor in the efficiency. Experiments by the author "have shown that the solution of oxygen from the air by water at its exposed surface does not remain concentrated at the surface, as was up to quite recently believed, but sinks as it is formed, toward the bottom layers of the water." This "streaming" is induced by cooling of the surface layer resulting from evaporation with consequent increase in density. Reverse upward currents of unexposed portions of water are formed to replace the surface layer and this mechanical mixing accounts

for the reaeration of the entire body of water. Laboratory experiments with deaerated water have shown this downward streaming is as effective at 10 ft. as at 1, 3 or 5 ft. It is more rapid in salt water where evaporation concentrates the salts in solution and speeds up the streaming effect.

Having established this streaming phenomenon, it remained to determine the actual rate of solution of oxygen from the air to the water surface. This was done by passing a large bubble of air of known volume upward through a long, narrow-bore tube containing deaerated water, also of known volume, repeatedly until saturation of the water by air has been attained.

By means of this method every part of the water is successively exposed to thin films of air. By measurement of the loss of pressure in the air bubble, the necessary data are obtained for computing the amount of oxygen dissolved in the water column. The rates and course of solution of oxygen from the air were found capable of expression by the formula:

$$w = w_1 - (w_1 - w_0)\, e^{-\frac{fat}{V}}$$

in which

w = concentration at the end of t minutes
w_1 = saturation concentration at the given temperature and pressure
w_0 = initial concentration at start when $t = 0$
f = coefficient of escape of gas from the water per unit of area
V = volume of water
a = area of surface exposed.

The coefficient f varies with temperature according to the equations:

Oxygen	$f = 0.0096$ (T-237) per minute
Nitrogen	$f = 0.0103$ (T-240) per minute
Air	$f = 0.0099$ (T-239) per minute

From this formula have been calculated the rates of solution of oxygen from the air by fresh or sea water from experimental data according to the following table:

Percentage of Saturation	Temperature						
	0°	5°	10°	15°	20°	25°	30° C.
	Time in Minutes						
10	0.3	0.3	0.3	0.2	0.2	0.2	0.1
20	0.7	0.6	0.5	0.5	0.4	0.4	0.4
30	1.2	0.9	0.8	0.7	0.6	0.6	0.6
40	1.5	1.3	1.2	1.1	1.0	0.9	0.8
50	2.0	1.8	1.6	1.4	1.3	1.2	1.1
60	2.7	2.4	2.1	1.9	1.7	1.6	1.4
70	3.6	3.1	2.8	2.5	2.3	2.1	2.0
80	4.7	4.2	3.7	3.4	3.0	2.8	2.6
90	6.7	5.9	5.2	4.8	4.4	4.0	3.6
99	13.4	11.8	10.4	9.6	8.8	8.0	7.2

Pressure = 760 mm. (moist bar).
1 inch = 2.54 centimeters. 1 foot = 30.5 centimeters.

Experimental investigations have shown that reaeration by "streaming" of normal sewage liquors in aeration tanks may be effected at the maximum rates of this table if the areas of the tanks are properly proportioned to their depths and if the surface of the liquors be kept continuously disturbed.

The air-bubbling method of aeration in activated-sludge tanks is, apart from mechanical agitation, a very inefficient process, because the bubbles are inclosed in a water film which does not change but passes up through the liquid to the surface, permitting absorption of only a minute amount of oxygen from the air bubble by the liquor in the tank. However, when "an unbroken bubble of air passes up through a column of water in a narrow bore tube as above described, the water film becomes continuously changed as the bubble of air ascends the tube and the most favorable conditions for the uniform and rapid mixing of the exposed with the unexposed portions of the water of the column are established." (In an editorial comment on this article it is stated "This is a point upon which it would be of interest to have further explanation for it is not clear why in one case an envelope should be formed round the air bubble and not in the other.") Aeration by streaming, the author adds, under any uniform set of atmospheric and physical conditions, proceeds in accordance with a formula similar to that given above for rates of aeration of thin films of water by the narrow bore and rising air bubble. J. K. HOSKINS

The Settlement of Activated Sludge

BY WILLIAM CLIFFORD AND M. E. DOUGLAS WINDRIDGE

Paper presented at Annual Summer Conference of Association of Managers of Sewage Disposal Works at Lytham St. Annes, July 7–9, 1932, and reviewed with discussion in *The Surveyor*, **82**, 75–77 (7/22/1932).

The control of the amount and condition of the activated sludge in circulation constitutes one of the difficulties of the activated-sludge process, particularly when sludge bulking occurs, that is, when the sludge does not settle readily from the liquid upon standing. Observations of the amount of settled sludge in graduated cylinders are unreliable for operating control under such conditions, when various expedients such as reducing the inflow of liquid, increasing the aeration, evacuation of watery sludge, addition of soil, etc., must be used to recondition the plant. The cause of bulking is generally attributed to under-aeration (although other causes are assigned by various cited authors) such as filamentous growths, industrial wastes, starches, sugars, yeast, etc.

Observations at the Wolverhampton Bio-Aeration Plant.—When the bio-aeration system was first installed, treating a very strong sewage, bulking was frequent, for which no satisfactory reason could be found.

Later a duplicate plant of the Sheffield system was installed, since which time the sewage has been weaker and less bulking has been experienced. However, when bulking did occur, it did not take place uniformily in all four sections of the plant, as would be expected if under-aeration or some specific constituent of the liquid were the cause. The explanation appeared to be that differences in the amount of sludge returned to the four sections of the plant were responsible for the variation. Experiments were made to test this point, the results of which are given in considerable detail. In these experiments the rate of settlement of the sludge was determined using 200-cc. graduated cylinders filled and well shaken at the start. Readings of the sludge volume were made at convenient intervals up to 24 hours. The total solids were also determined by weighing a portion of the evaporated sample in the usual way.

Experimental Results.—The first recorded experiment is a typical series of results of observations from each of the four aeration channel sections, showing the wide variation in the shape of the settlement curves, the difference ranging, for example, in 30 minutes' standing from 94.5 to 41 per cent of settled sludge. The second experiment was designed to show the effect of the diameter of the vessel on the time of settlement and indicates that settlement is much more rapid in wide vessels than in narrow ones. Thus at the end of two hours in cylinders of 4.19, 2.41, 1.84 and 1.34 inches diameter, samples of the same sludged settled to 50, 65, 72 and 77.5 per cent of the volume of the respective cylinders, an effect ascribed to surface contact of the cylinder walls.

The next experiment records observations on the effect of depth of the vessel used for settlement, from which it appears that in vessels of different depths the surface of the settled sludge falls the same fraction of the total depth in the same time and not at the same rate (*e. g.*, in feet per second).

Experiments are next recorded investigating the relation between the concentration of sludge and its rate of settlement, using both ordinary activated sludge and reconditioned sludge. These data indicate that the time required for settling increases with concentration but that equal weight increments of sludge concentration above a certain point increase the time element disproportionately. Thus increments by weight of 0.053 gram of sludge up to 0.263 gram in 100 cc. of liquid increased the volume on two hours settling from 3.5 to 5.5 per cent but the next increment of 0.053 gram of sludge increased the volume by 28.5 per cent. Further results demonstrate the extreme slowness of settling of activated sludge in high concentrations, by weight, as shown in the following table:

Grams of Sludge in 100 Cc.	Volume of Settled Sludge After Settlement for 1 Hr.	2 Hr.	3 Hr.	4 Hr.
0.119	18	14.5	13	12
0.238	69	50.5	34	27

Further experimental data indicate the similarity in the rôles of settlement of ordinary sludge and reconditioned sludge. However, the weight concentration of the latter is much greater than that of the former or, in other words, the "effective density" of reconditioned sludge is greater than that of ordinary sludge. The same effect of increasing sludge density on the rate of settling as observed above for ordinary sludge is noted in the case of reconditioned sludge. For all sludges examined it was found that an increase in the weight of sludge solids per 100 cc. of liquid produced more than a proportionate increase in the volume of settled sludge for all periods of settlement up to six hours. Beyond a certain weight of sludge, roughly 25 per cent on two hours' settlement, a further small increase produced an enormous increase in volume. Hence the phenomenon of bulking may be largely a result of too much sludge, regardless of the condition of the sludge or its state of aeration.

Experiments are next presented to show the improvement in settling properties of sludge of various concentrations brought about by aeration, the greatest benefits accruing to sludges of lowest concentration.

Practical Application of the Results.—The effect of the diameter of the vessel used for settlement indicates that results obtained in small cylinders must be interpreted with caution when applied to large tanks. The observed effect of depth of vessel on settlement indicates that whatever the depth of settling tank, under quiescent conditions a sludge of the same moisture content will result. In actual practice deep settling tanks may be of advantage because of more nearly quiescent conditions in the lower parts.

Bulking may be controlled by keeping the volume of sludge circulating in the plant below 25 per cent on two hours' settlement. Ten per cent of sludge seems to be the best amount for purification and settlement at Wolverhampton and this practice has resulted in considerable operating improvement. Prolonged aeration has the same beneficial effect on bulking as reduction in weight concentration and could be used where an ample supply of air is available, although several days' aeration of the same sludge may be required to produce any marked change.

A certain residual volume of sludge should be maintained in settling tanks to allow concentration, but if this sludge volume exceeds the quiescent space of the tank, some sludge will be discharged with the tank effluent. In any event the larger the amount of sludge maintained in circulation, the greater is the capacity of settlement tanks required and the greater the volume of sludge to be removed.

From experimental data presented it is concluded that for short settlement periods the heaviest sludge is obtained by settling the liquid containing the smaller quantity of sludge, although for periods of 24 hours' settlement the thickest sludge is obtained from the most concentrated sludge liquid.

Settlement of Inorganic Substances.—A further experiment, employing inorganic substances such as ferric and aluminum hydroxide, demonstrates the phenomenon of bulking to be a physical effect. By use of these inorganic flocs a critical concentration was obtained above which the rate of settlement was seriously retarded, just as in bulking activated sludge. The conclusion is that any particles which have the same characteristics as activated-sludge particles will settle in a similar manner and exhibit the same bulking phenomenon. Hence biological growths observed when bulking occurs are in no way the primary cause of this condition but may be induced by these changed conditions of sedimentation.

Discussion.—In opening the discussion of this paper Dr. E. Ardern stated that the bulking problem had been solved at the Manchester plants. He ascribed the bulking in certain sections of the Wolverhampton plant to insufficient aeration because more sludge was going into these sections. He did not consider that the proportion of sludge was the dominant factor in bulking but he did agree that the sludge should not exceed 20 per cent and that below this critical point the volume of sludge was not important.

Mr. J. H. Edmondson of Halifax gathered that the author believed the concentration of the sludge in the activated-sludge tank caused bulking, a condition which might be peculiar to the Wolverhampton plant. At Halifax it was observed that where the iron content exceeded 0.6 p. p. m. bulking commenced and that when the iron reached 20 p. p. m.—in the colloidal state—bulking was serious. The determination of the iron content was, therefore, one of the control tests.

Mr. J. Bolton (Bury) did not consider the bulking problem solved and disagreed with the view that bulking was due to under-aeration, because no amount of reaeration would bring bulking sludge back into condition. In the two Bury plants, bulking was never experienced in the one treating domestic sewage only, while constant trouble occurred in the other, where trades waste such as tannery and wool scouring liquors were in the sewage. Wastes from a large winery also caused a great deal of bulking. In experimental work he could never induce bulking by over- or under-aeration but if milk waste were added bulking could be quickly obtained. Uric acid also caused bulking most readily, all of which convinced him that bulking was caused by certain chemicals in the trade wastes part of the sewage flow.

Mr. F. R. O'Shaughnessy of Birmingham stressed the importance of various forms of activated sludge dealt with and the complexity of the factors which contribute to the bulking phenomenon. He wished to correct the impression that he believed bulking was solely a plankton complex and stated it as his opinion that no simple formula could be given as the cause of sludge bulking. He agreed that the percentage volume on settling alone was not always a satisfactory criterion of operation

but that the weight of sludge present was the significant factor, as Dr. Mohlman of Chicago had suggested. A more useful factor for control was the sludge density—a combination of percentage volume after a given time of settlement with the mass of the sludge in the volumes after settlement.

Mr. F. W. Harris of Glasgow pointed out that changes in the constitution of the sludge necessarily involved changes in its physical character, especially of its density which in turn affected its settling properties. There was a limiting maximum percentage of sludge which, if exceeded, resulted in inefficient aeration conditions, because of the demand made upon the available dissolved oxygen. His experience was that if by increased sludge concentration the dissolved oxygen in the supernatant liquid was reduced, bulking invariably followed.

Mr. W. D. Scouller of Huddersfield stated that in the plant he was operating bulking had never occurred, but in an experimental plant where bulking was obtained he could treat three times the volume of sewage when bulking was taking place as he could under normal conditions. He did not consider that the type of bulking produced when one approached 20 per cent of sludge in the aeration unit was the ordinary type experienced where bulking produced 90 per cent of sludge after two hours. He had found iron content not to be a factor so long as the amount did not decrease.

Mr. W. H. Hoyle of Wakefield related experiences directly the opposite of those of Mr. Bolton—bulking in the plant treating domestic sewage and none in the one handling a mixture of sewage and trade waste. He believed that sugar in the sewage created a culture medium for the filamentous growths associated with bulking. He could tell by microscopical examination of the sludge for filamentous growths whether sludge was bulking or not.

In his closing remarks the author commented briefly on the various points raised in the discussion and re-emphasized some of the statements made in the body of the paper.

J. K. HOSKINS

Sewage Purification at Guildford

ANON.

From a brochure prepared by J. W. Hipwood, the borough engineer, and abstracted in *The Surveyor*, **82**, 78–79 (July 23, 1932).

The new plant, recently placed in operation serves an estimated population of 39,000 contributing a dry weather flow of 1.5 m. g. d. and consists of detritus chambers, bar screens, primary and secondary sedimentation

tanks, biological filters and humus tanks with storm water tanks provided for wet weather flows. The total cost of the works is about £47,000.

Detritus Tanks.—Three tanks each 50 ft. long, 7.5 ft. wide and 2.5 ft. deep have a combined capacity of 17,580 gallons. Grit is drawn off through three valves to which the tank floors slope.

Screens.—The bar screens are inclined to the direction of flow with a clear space of $1^1/_2$ inches, and are cleaned by hand. Screenings are removed to a screenings pit and then hauled to the land and plowed in. After passing the screens the sewage flow is gauged and passed through the inlet channel to the settling tanks.

Primary Sedimentation Tanks.—The distributing channels serving these tanks have weirs 46 ft. long, over which the inflowing sewage passes. The tanks of the horizontal, continuous-flow type are each 60 ft. square and 9 ft. deep with a combined capacity of 365,900 gallons. Outlet weirs are also 46 ft. long, protected by scum plates of galvanized iron. Sludge is removed by revolving scrapers which move the material to the center of the tanks, where it is drawn through 9-in. sludge pipes to a sludge well.

Secondary Sedimentation Tanks.—These three tanks are 90 by 46 ft. in plan and 8 ft. deep and designed to provide further sedimentation and equalization of the sewage strength throughout the 24-hr. period. This mixing is effected by influent weirs located at both the end and sides of the tank, thereby providing varying times of flow to the outlet. The floors slope to central sludge-collecting channels through which the sludge is removed by hand to the sludge well.

Biological Filters.—Half of the effluent from the secondary settling tanks goes to the biological filters, the other half to the land. The four filter beds cover an area of $1^3/_4$ acres and vary in depth from 6 to 6.5 feet. They contain 17,360 cu. yd. of shingle from $1^1/_2$ in. to $^1/_2$ in. in size underdrained by aerating tiles leading to central effluent channels. Sewage is conveyed to the filters by traveling distributors which are fed from still supply troughs. The distributors are driven by the weight of the sewage alone.

Land Treatment.—The half of the settled sewage is treated by broad irrigation on 100 acres of land at the rate of 8070 gallons per acre daily. The principal crops raised are oats, marigolds and brussels sprouts.

Humus Tanks.—Four of these tanks of the horizontal-flow type receive the effluent from the filters where the partially oxidized solids are removed. The tanks are 70 by 36 ft. in plan and vary in depth from 2 ft. at the inlet to 9 in. at the outlet, with a total capacity of 93,200 gallons. Each tank has three bays through which the sewage flows in succession before discharge to the river. Sludge is removed through a central channel and pumped to join the incoming crude sewage at the grit chambers.

Storm Water Tanks.—Three old sedimentation tanks built in 1895 are to be used for storm water. These tanks are 70 by 50 ft. in plan and have a combined capacity of 0.36 m. g. The effluent will be discharged to the land through the original floating arms.

Sludge Disposal.—Sludge from the various units gravitate to a sludge well, from which it is pumped by compressed air to a land area of 18 acres.

J. K. HOSKINS

Unusual Features of Sewage Treatment at Bradford, England

Public Works, **63**, 12 (Aug., 1932)

The third edition of the report of Bradford concerns the construction and operation of its sewage treatment plant.

The disposal works receive sewage from a population of 287,400. The dry-weather-flow averages 63 gal. per capita (18 m. g. d.) which increases to 96 m. g. d. in wet weather, the average being 23.75 m. g. d. The sewage contains large amounts of wool-washing wastes, which give high rates of flow during the day and also troublesome quantities of wool fat. The crude sewage contains 890 p. p. m. of grease as an average, but much more than this when the wool-scouring wastes are being discharged. The sewage also contains coarse grit, lumps of clotted cotton waste, wool and large rags. These are intercepted in a tank, from which they are dredged. The finer mineral material is retained in the settling tanks, where floating matters are intercepted by scum boards.

For precipitating the wool fat, lime was used originally, but was replaced by ferric sulphate and, later, by sulphuric acid, which now is used, being manufactured at the sewage works. By the use of sulphuric acid, soaps are cracked and dissolved organic matter is precipitated, together with wool waxes and suspended matter. Formerly the sewage was acid-treated 24 hours daily but the expense was great and the filtration of such acid sewage presented difficulties. The best results from filtration were found when the pH of the tank effluent was about 6. At present, acid is added to the sewage only when wool suds are reaching the plant; it is not added at night or over week-ends, or in very wet weather.

The sludge from both detritus and sedimentation tanks is pressed into cakes by 128 sludge presses. Coarse grit, paper, rags and other fibrous matters are included, as they aid the pressing. Before being pressed, the sludge is heated in vats by steam coils, in order to expel the grease in pressing. The grease and water are then expelled and the dried cake is hauled to a drying area.

The tank effluent is treated on 53 acres of filters 6 ft. deep, giving a

cu. yd. of filter for 35 gal. of tank effluent per day. Hard Yorkshire coal is used as a filter medium. It does not deteriorate, is the cheapest medium available and loses no calorific value from long service. During the general strike of 1926, the gas and electric services in Bradford were maintained at full output through use of the coal from the filters and both factories and homes in the area were supplied with this coal; 200,000 tons being sold and afterward replaced.

H. W. STREETER

Mechanical Equipment in Sewage Treatment Work—Grit Chambers and Bar Screens

BY A. PRESCOTT FOLWELL

Public Works, **63**, 13–16 (June, 1932)

Rain or flushing water from streets generally carries mineral matter which must be removed if sewage is pumped and should be removed if it is treated, though many treatment plants receiving only sanitary sewage are operated successfully without pre-removal of grit or large objects.

Grit Chambers.—It is generally considered that all but very fine grit will settle but if sewage has a velocity of 1 ft. per sec., which is the accepted velocity of flow through grit chambers. To maintain this velocity with hourly and daily variations in flow, two or more channels are provided, so designed that when the velocity exceeds 1 ft. per sec., part of the sewage is diverted into a second channel. The same result is obtained by manual operation.

The silt deposited in grit or detritus tanks is removed in the smaller and in some of the larger plants by hand shoveling and flushing, but most recent large plants have installed mechanical equipment for this purpose. One type is a fixed or movable crane, which lowers into the grit chamber a grab or hand-filled bucket, which then is raised and emptied into a truck. Another consists of a monorail mounted over the chamber and carrying a bucket which can be lowered. Another device, called a detritor, contains a collecting mechanism in the bottom of a square grit chamber, which pushes the grit into a channel, whence it is drawn by a reciprocating rake upward to a drainage deck.

For the final removal of silt to a storage place, a monorail and bucket carrier, or a belt, bucket, scraper, or screw conveyor, may be used. Some plants have pneumatic ejectors for removing grit to distant points—as far as 1000 ft. with an 80-ft. rise in one case. The air used for conveying is also used to clean the ejector and discharge pipe.

Bar Screens.—It has been customary to remove large floating matters

from sewage by racks or screens consisting of flat or round bars of iron or steel, or occasionally of wood. These are generally spaced $^1/_2$" to $2^1/_2$" apart and set at an angle of about 30° with the vertical to facilitate cleaning. The screen is usually designed so that the total submerged area between bars will give a velocity of 3 ft. per sec. during maximum flow.

Although bar screens are still often cleaned by hand rakes, several types of mechanical rakes are available and coming into general use. There are three general types, two for use with the common flat screen and one requiring a curved screen.

The more common type consists of a series of rakes, the ends of which are attached to a pair of endless chains which continuously move the rakes slowly upward over the face of the screen, carrying the screenings to the top of the screen, where they are dropped into a conveyor or bucket or onto a draining platform. In the second type a single rake moves up the screen, delivers the screenings, is withdrawn horizontally and descends to the bottom again. A reciprocal form of rake is carried on one arm of a jointed frame operating on the pantograph principle. The third type consists of rakes revolving about an axis and engaging the bars of a screen curved to the same radius. The firms manufacturing these several types of screen are named and illustrations of them are given.

In most small plants the screenings are deposited on a draining platform at ground level or in cans, wheelbarrows, etc., to be removed at intervals by hand. In large plants belt or other conveyors are used, or the screenings are deposited in hoppers for intermittent removal by trucks. In a plant recently completed by the Westchester County Sanitary Sewer Commission, large pneumatic ejectors are used, capable of passing a 2" × 4" timber 2 ft. long.

A following instalment will deal with sedimentation and digestion tanks.

H. W. STREETER

Insuring Glass Covers for Sludge Beds

Public Works, **63**, 23 (Aug., 1932)

An inquiry as to the insurance of glass covers for sludge beds has yielded the following information, in part, on this subject.

At Kitchener, Ont., 32,000 sq. ft. of glass are insured against damage from weather to a total value of $2400 for $59.25 per year. The glass covers of the Marion, Ohio, sludge beds have been insured at an annual premium of $200 for hail and wind damage to these and also to all of the plant building and fire insurance of their contents, the total insured value being $65,000. It is understood that the insurance companies will not insure the glass covers alone but require inclusion of the other buildings to

cut down the rate. Ithaca, N. Y., applied for insurance but the rates were so high that they decided to carry the risk themselves. A representative of a large manufacturer of greenhouses has expressed the opinion that insurance of this kind is unnecessary and too expensive to be practicable.

Insurance companies seem to agree that most insurance of greenhouses against hail is carried by the Florists Hail Association of America, whose rates are given for four zones, each including several states. For all states east of the Mississippi (Zone A) the rate is 7.5 cents per 100 sq. ft. For other states the rate varies from 10 to 20 cents per 100 sq. ft. These rates are for double-strength glass; for single strength each rate is doubled.

Windstorm insurance on glass is quoted by the Pennsylvania Lumbermen's Mutual Fire Insurance Company as being $7.50 per thousand per year, with a 25 per cent return on expiration of the policy. This form of insurance must be written under a blanket form with a full co-insurance clause.

H. W. STREETER

Stream Pollution by Coal Mine Wastes

Water Works Eng., **85**, 202 (Feb., 1932)

In the spring of 1925 the United States Bureau of Mines undertook the study of stream pollution by coal mine wastes. A stream in a district thought to be representative of the average sulphur bituminous coal field and another stream in a high sulphur district were selected for study.

Pollution resulting from fluctuations in the volume and strength of acid wastes may cause great trouble in water purification, especially in those streams ordinarily near the neutral point in acidity. Although an acid water may be neutralized chemically, a water of correspondingly increased hardness is the result. This water may next be softened, but if the original acidity is above a certain high value, softening does not solve the problem. The amount and nature of the softening chemicals remaining in solution cause "foaming" or "priming" in boilers.

The accepted theory of acid formation in coal mines is first, an oxidation of iron pyrite, commonly known to miners as "sulphur." The result is iron sulphate, which is readily soluble in water, as contrasted with the original pyrite. Subsequent oxidation and hydration result finally in the formation of varying amounts of iron oxide, commonly known as "sulphur mud," and definite amounts of free sulphuric acid.

Pyrite occurs in widely varying forms and quantities in coal, also in top or bottom strata. As a rule, bottom coal and often the fire clay immediately beneath the coal have the highest percentages of pyrite. Not

infrequently the top stratum or coal also contains relatively large amounts of pyrite. These conditions seem to remain fairly constant for the different coal beds, but wide variations are to be noted in different sections of the same mine. As might be expected, therefore, the acidity of water may and usually does vary considerably in different mines in the same bed, and even in different parts of the same mine.

Old worked-out sections of a mine are almost invariably the sources of the most highly acid water, and information from many mining men seems to agree that pillar-drawing generally results in increasing the acidity of water, as indicated by its color and its subsequent corrosive effect on metals.

Studies conducted in mining areas of a high pyrite content show that the effluent from these areas has usually between two to five times as high an acidity as is considered average acidity. Three of the total of 31 mines visited had non-acid water coming from them.

Outside "gob" piles are believed to be an important contributing factor in the general stream pollution problem. They are almost invariably composed largely of the pyrite thrown out when mining or cleaning coal. They are exposed to the most favorable condition for acid formation, so far as contact with moisture and air is concerned, and thus the three factors necessary in the reaction are present. As a rule, water is to be seen trickling from these refuse piles, and when pools of water can collect around them, this water is always highly acid.

The probable effect of rock-dusting as a method for decreasing acidity by neutralization has been tried at the Mather Collieries Co., Mather, Pa. The mine has been completely and heavily rock-dusted and samples were taken wherever water was known to be in and about the mine. Of the 21 samples collected, only five were found to be acid.

Although it may be true that rock-dusting has resulted in changing an originally acid water to one of alkaline character, the evidence points to the probability that in this case the water was never acid generally.

The effluent water from mines that were abandoned and caved, or otherwise sealed, either were not acid or only slightly so. In a few cases, water from such mines has been used as a source of water supply for domestic and drinking purposes. As the accepted theory of acid formation in coal mines requires the presence of water, oxygen and iron sulphide together, it naturally follows that if any one of these three constituents is absent, no acid will be formed. In a previous report by the Bureau of Mines the following results were noted: (1) That no sample of water from behind seals contained free sulphuric acid and only one had sulphates of iron in solution, (2) that every sample in open sections of long standing, in five mines was acid and highly so, as a rule. Usually gas samples from behind seals in these mines show the presence of oxygen to be less than 1 per cent.

The results of the study indicate clearly that, where possible, exclusion of air from mines or parts of mines will result in preventing acid formation.

C. T. WRIGHT

All Sewage Solids Burned

Public Works, **63**, 45–46 (July, 1932)

London, Ontario, has nearly completed a sewage treatment plant containing several features of unusual interest. This plant is one of three plants treating the city's sewage. The total population of the city is about 73,000, and the maximum sanitary sewage flow about 7 m. g. d., of which this plant treats about 4 m. g. d. from approximately 50,000 of connected population.

In 1926, plans were adopted for removing the activated-sludge solids by mixing them with raw sewage and passing the mixture through fine screens. The results have shown that most of the solids of the activated sludge adhere to the grosser solids of the raw sewage and are screened out with them. If some sludge passes the screens, it adds but slightly to the amount of activated sludge intentionally added to the raw sewage.

The screenings from the fine screens, as well as from the bar screens, and grease from the grease trap, are burned together in an incinerator. The ash from this and sand from the grit chamber are used for land-filling.

The general treatment is as follows: The gravity sewage enters the plant through a 48″ sewer and the pumped sewage through a 20″ sewer. When the combined flow exceeds 5 m. g. d., the excess is diverted to a storm sewage tank, the effluent of which goes to the river, while the sludge is returned to the main flow just below the grease trap.

From the diversion weir the main flow passes into a grease trap. The grease from this trap passes through a press and is charged into the incinerator. The grease trap effluent, after receiving the sludge from the storm sewage tank, passes through a grit chamber.

The grit from the grit chamber is washed and used for land-filling. The effluent receives the excess activated sludge and passes through a bar screen, and from this through a fine screen.

The screenings from both bar and fine screens will be pressed to remove part of the water and burned in the incinerator. The effluent receives the necessary return sludge and passes to the aeration tanks.

After studying the various types of screens, a panel type, known as the Hankin fine screen, was selected. The unit is made up of six screens, each 5 ft. wide by 18 in. deep, set radially around the circumference of a drum. Each screen is made up of $^1/_8$″ square mesh galvanized iron wire, reinforced with $^1/_2$″ steel wire, held in a heavy steel frame. The drum revolves

slowly and the screenings on the rising panels drain off much of the moisture, and on reaching the top are jarred off into a hopper. From the hopper the screenings, having about 87% moisture, are carried by a screw conveyor to wire baskets, where they are drained further and then placed in the incinerator.

Experiments are being made with pressing screenings in a tapered perforated wrought iron pipe. The screenings are fed into this pipe from a hopper and are pushed forward by a piston under pressure, thus forcing out part of the water, in the screenings, during the process. Using a pressure not exceeding $1^1/_2$ tons, the moisture content has been reduced from 87 to 75 per cent.

The incinerator, after being started with fuel, burns the screenings without additional fuel. It has a fire grate area of 3 square feet, and a drying-hearth area of 4 square feet. Screenings are dumped onto the drying hearth and drawn forward onto the fire by hand. The incinerator is expected to burn ten tons of wet screenings per day.

The cost of the plant has been $54,557 for preliminary treatment works, administrative building and operator's residence, and $107,172 for the aeration, reaeration and settling tanks, including piping, compressors, pumps and housing, and it is estimated that $54,450 will be needed to complete the plant. This total of $217,000 represents a cost of $43,400 per million gallons capacity or $4.34 per capita of connected population.

C. T. WRIGHT

Heat Losses from Sludge Digestion Tanks

BY WILLEM RUDOLFS AND H. J. MILES

Civil Engineering **2**, 481 (1932)

Sludge-digestion tanks at 70–80° F. are generally heated from the gases of decomposition and the gas is most always sufficient for the purpose. Question arises as to whether the same situation obtains in digestion at at 120° F. Tests to determine heat losses were directed first to ascertain the relation between losses at the two temperatures.

The procedure involved the use of 1-gallon earthenware containers. The receptacle with digested sludge contents was heated to 50° C. (and other initial temperatures) and then placed in an electric refrigerator with temperature maintained by thermostatic control at 0° C. Temperatures of the sludge were read at 15 min. intervals. General findings were: (*a*) The cooling curves (temperature of sludge at different time intervals) for different initial temperatures each showed a period of "lag" during which "the rate of cooling increased with decrease of temperature," and followed by a lessened rate of cooling. This "lag" varied from $1^1/_2$

hrs. at 49° C. (initial temperature) to 3 hrs. at 15° C. The "lag" as noted is ascribed in the first place to the low heat conductivity of sludge and to the time needed to build up a heat gradient. A second cause of "lag" is found in the physical characteristics of the container.

(*b*) The observed low heat conductivity of sludge is regarded as justification for the usual practice of placing heating coils near the walls of the digestion tank. The question of location is affected by heat stratification (a difference of 7° F. within one or two feet of the heating coil is cited). Doubt is cast upon the propriety of placing heating coils near the bottom of the tank because sludge at this point is the best digested and needs heat the least.

In the foregoing experiments, temperatures were read at the center of the jug. A second set of experiments was directed to the average cooling rate of the entire contents. In this series ten metal containers with tight covers were charged with 1-liter samples of digested sludge and heated and cooled as before. One of the containers was used as a control. The remaining containers were taken from the refrigerator each at different time periods and shaken before the temperature was read. Temperature of the control was read simultaneously. The results of these experiments showed a "lag" but shorter than in the first set.

Experiments as described were also conducted with digested sludges having 4 per cent and 11 per cent solids, and likewise with fresh solids (4 per cent solids). The findings here were that neither concentration of solids within usual limits nor the freshness of solids affected the rate of cooling, although tap water was found to cool more rapidly than sludge. Low heat conductivity of sludge is therefore ascribed to the inert content.

The laws of heat loss were found to conform closely to the expression $\phi = \phi_1 e^{-KT}$.

ϕ = degrees difference (C) between sludge and surrounding air at given time
ϕ_1 = initial value of ϕ
T = hours for cooling from ϕ to ϕ_1
K = constant varying with cooling material and size shape and composition of container.

From this formula it follows that the rate of cooling $\left(\frac{d\phi}{dT}\right)$ varies directly as the temperature difference ($K\phi$) between the heated sludge and the surrounding air. Thus, comparing the rate of cooling of sludge at 120° F. with sludge at 70° F., it follows that the rate of cooling at the higher temperature is twice that at the lower temperature when the air is at 20° F. and six times when the air is at 60° F.

The foregoing statements apply to the rate of cooling. When extended to the total heat loss with digestion accomplished in 40 days at 70° F. in

30 days at 82° F. and in 10 days at 120° F., it follows that when the air is at 20° F. the ratios of total heat losses are, respectively, 1.00, 0.93 and 0.46 while with air at 60° F. the ratios are 1.00, 1.65 and 1.50. In turn this leads to the conclusion that with substantially equal amounts of gas produced during digestion at various temperatures, the gas will be sufficient to maintain the higher digestion temperatures.

Conclusions quoted from the paper are:

"1. The rate of cooling of sludge in air is directly proportional to the difference in temperature between sludge and the surrounding air.

"2. No difference between the rate of cooling of fresh solids and ripe sludges of varying concentrations between 4 and 11 per cent of solids could be detected, but there was some difference between the rates of cooling of sludge and water.

"3. As the rate of cooling sludge is less than that of water, it would appear desirable to concentrate the sludge before digestion.

"4. The sludge in the center of a container cools considerably, more slowly than the entire mass of sludge as a whole, but both follow the same law of cooling." FRANK TOLLES

A Neglected Sewer System Revamped as Unemployment Relief

Public Works, **63**, 51 (July, 1932)

At Lancaster, N. Y., a village of about 7000 population, there was never any direct supervision over the sewerage system or treatment plant, previous to 1928. The treatment plant, which had been built in 1908, consisted of two very deep grit chambers, wire screens, two covered septic tanks operating in parallel and four contact beds over which the tank effluent was to be distributed by Miller Potter siphon apparatus. The effluent was discharged into Cayuga Creek through an outfall sewer provided at the outlet with a swinging flood gate, as a rise of two feet in the creek caused it to back up into the plant. Pumps had been provided for lifting the sewage to the contact beds, but their capacity was approximately $^1/_{25}$ of the sewage flow during storms, and the sewage filled and overflowed the plant at such times.

The grit chambers, which were $9^3/_4$ ft. deep, acted as septic tanks, and scum formed on them, blocking the screens and giving off very offensive odors. The septic tanks were filled with sludge to the flow line, and the crude sewage was flowing in channels across the top of the sludge and being delivered in this state onto the contact beds.

The treatment plant was rebuilt with unskilled labor as a means for unemployment relief. The grit chambers were filled with stone from the

contact beds to reduce the depth from $9^3/_4$ ft. to $1^1/_2$ ft. Coarse bar screens were installed between them and the septic tanks. The outlets of the tanks were adjusted to raise the water level from 6 ft. to 9 ft. above the floor. The two centrifugal pumps were rebuilt and a third having three times their combined capacity was added to raise the sewage into the creek. A chlorinator and chlorine mixing chamber provide for treating the effluent with dosages ranging up to 100 pounds a day. The four contact beds were repaired and filled with new stone on an adequate underdrainage system, at a total cost of about $15,000.

The sewer system was in an equally bad condition. In undeveloped streets many of the "Y's" were without covers, or the covers were not tight and water and sand entered. Practically all of the pipe joints were without any caulking whatever. Along a state highway, connections had been carried from each "Y" to beyond the pavement, and during rains, water from the ditches beside the road ran through sink holes into all of them. As a result clogged sewers were numerous.

With $10,000 obtained from the state's temporary emergency relief administration, 4.2 miles of sewer were cleaned, flushed and repaired, and brooks which were flowing over the sewers were returned to their old channels. The sewage flow has been reduced 50 per cent.

C. T. WRIGHT

What Is Sewage Disposal?

BY HENRY W. TAYLOR

American City, **46**, 67–70 (April, 1932)

Sewage is 99.99 per cent water. However, the other one-hundredth of one per cent pollutes the entire mass, creates a vast nuisance and is removed only with difficulty. To remove this small amount of undesirable matter from sewage, several methods are employed, some affording only partial removal, others giving more complete treatment. The purpose of any treatment is to lighten the load on the stream or other body of water which ultimately receives the discharge from the sewage treatment plant.

Screening removes the coarser solids and reduces the putrescible organic content by about one-tenth. Settling tanks remove more than three-quarters of the settleable solids and reduce the oxygen demand of sewage by about one-third.

Sprinkling filters are employed to treat the overflow from settling tanks. This type of treatment supplies oxygen to the sewage by absorption from the air in the filter bed, and through the activity of oxidizing bacteria reduces the oxygen demand of sewage by about four-fifths.

Sand filters remove practically all solid matter and about 90 per cent of the oxygen demand. They function in the same manner as sprinkling filters.

Activated sludge serves the same purpose as sprinkling filters. The oxygen is supplied by forcing air through diffusers or by mechanical agitation. Ninety per cent of the oxygen demand is removed in this process.

Disposal of the sludge formed in these various processes is a problem in itself. It can be met by digestion in sludge tanks with consequent drying on sand beds.

All the above mentioned processes remove bacteria from sewage in more or less degree. Chlorination is effectively employed for this purpose. It is also somewhat effective in reducing the oxygen demand of sewage.

E. HURWITZ

Sewage Sludge as Fertilizer

BY T. C. SCHAETZLE

Municipal Sanitation, **3**, 324–327 (Aug., 1932)

Shortly after Akron's new sewage treatment plant was put into operation, the works management was confronted with the problem of disposal of the dried sludge. A campaign to interest the farmers of the community resulted in the removal during 1931 of 10 per cent of the air-dried production. The county farm agent, however, hesitated to recommend use of the sludge on the basis of such data as were available from other sources. Experiments therefore were conducted to determine the fertilizer value of the sludge. Two almost identical plots were used, one sludged, the other unsludged and used as a control.

The sludge removed from the beds during 1931 averaged 47.6 per cent moisture, 1.6 per cent nitrogen as ammonia, 9.4 per cent ether soluble, 0.5 per cent potash and 0.67 per cent phosphorus as P_2O_5. Forty tons of sludge per acre were spread on the sludged plot. The plots were carefully attended and farmed identically in every way.

The results of these experiments indicated that the sludge was of no value in growing peas, head lettuce, spinach, peppers and cucumbers; it was of doubtful value in growing endive, parsley and potatoes; of moderate value for Kentucky wonder beans, onions and cabbage; of real value for curled lettuce, turnips, white bush squash, tomatoes and pumpkins; and of exceptional value for lima beans, celery, stringless beans, parsnips, beets, radishes, Hubbard squash, cantaloupe, carrots and sweet corn.

E. HURWITZ

Separate Sludge Digestion Works at Wichita, Kansas

BY F. M. VEATCH

American City, **47**, 58–59 (August, 1932)

The new sewage treatment plant at Wichita, Kansas, was placed in operation in July, 1932. It is designed to care for a flow of 18 m. g. d. from an expected population of 160,000 by 1940.

The plant consists of bar screens, grit chamber, aeration tanks, settling tanks, sludge digestors and drying beds.

The screenings from the bar screen are deposited on a belt conveyor and discharged into the hopper of a gas-fired incinerator.

The grit chambers are provided with rakes which push the grit into a collection hopper where it is washed with clean water and flushed into the drainage canal.

Grease is removed from the sewage in an aerating tank of the ridge-and-furrow type placed ahead of the settling tanks.

The settling tanks are designed to give a two-hour detention period and are provided with sludge scrapers and scum skimmers of the Link-Belt type.

There are three digestors with a total capacity of 320,000 cu. ft. Each digestor is provided with a separate gas-fired hot water boiler. The gas generated during digestion is collected in a 25,000 cu. ft. gas holder and is utilized in the incinerator and the hot water boilers.

The digested sludge is dried on 36 beds with a total area of 108,000 sq. ft. The dried product is to be used as fill in the low areas about the plant. It will be removed from the beds by hand and hauled to the dump by a gasoline tractor and ten dump cars.

A complete laboratory is provided in the building housing the boilers, sludges, pumps and meters.

The plant cost approximately $410,000 or about $2.65 per capita based on 160,000 population.

E. HURWITZ

City Liable for Damages Caused by Sewage Disposal

Public Works, **63**, 31 (June, 1932)

The City of Barnesville, Ga., emptied its sewage into a stream flowing through the land of one Parham, who brought action against the city to recover damages. The city carried the case to the Court of Appeals, which ruled that a landowner may recover damages for the impaired rental value of his land and tenant houses thereon, resulting from a continuing nuisance

caused by discharge of obnoxious sewage into a stream flowing through his land, and also for damage to him while living in a dwelling house on the land, resulting from contaminating atmosphere, poisonous gases, offensive odors and vapors caused by this contamination of the stream.

H. W. STREETER

The Oyster Industry and Waste from Pulp Mills

Science, **75**, No. 1939, Supplement 10 (1932)

A brief account of a report by the U. S. Bureau of Fisheries of investigations by Hopkins, A. E., Galtsoff, P. S., and McMillin, H. C., on the effects of sulphite waste liquors on oysters. The waste liquor was found to produce experimentally a high death rate, a poor quality of meat and lack of shell growth. These abnormalities are characteristic of the oyster beds in Oakland Bay on Puget Sound which receives the waste waters from a pulp mill. It was also found that barnacles, mussels and certain plants did not grow on boats or other floating equipment in water containing sulphite liquor. Sewage and sawmill products were also investigated but were held not to be responsible for the condition of the oyster beds. It is believed that the pollution of the water in Oakland Bay by sulphite wastes has caused the death of practically every young or larval oyster. *Summary of Current Lit.* (British) Water Pollution Research Bd., **8,** Abs. No. 1033 (Aug., 1932).

Bacterial Denitrification: An Historical and Critical Survey

BY B. LLOYD

J. Roy. Tech. Coll., Glasgow, **2**, 530 (1931)

Bacterial denitrification occurs during organic decomposition, certain bacteria using the combined oxygen in nitrates for respiration and liberating the nitrogen as a waste metabolite. Nitrites, hyponitrites and the oxides of nitrogen may be formed during intermediate stages; only certain bacteria under conditions of free oxygen deficiency carry the reduction to the final stage. Carbon dioxide is also produced, but the greater part of it is retained as carbonate. The evolution of nitrogen is accompanied by an increase in alkalinity of the medium. Enzyme action is discussed; some reductase enzymes which reduce nitrate to nitrite have been isolated. A list of denitrifying organisms is given. Conditions affecting denitrification are: temperature, with increase of which the rate of reduction rises

to a maximum, the optimum temperature varying with the organism; pH, initial alkalinity favoring denitrification; aeration and high initial concentration of nitrate, which have a retarding effect. Media for denitrifying bacteria and a list of food materials favorable to their growth are mentioned. Some nitrates, *e. g.*, those of strontium, sodium, potassium and nickel, are more readily reduced than others. Certain substances, *e. g.*, sulphuric acid, calcium cyanamide, caustic lime and phosphoric acid are inhibitory. Indirect denitrification may also occur; in this the production of nitrogen is the result of a secondary chemical reaction following bacterial action. *Summary of Current Lit.* (British) Water Pollution Research Bd., **8,** Abs. No. 1044 (Aug., 1932).

Slurry Reclamation

Coll. Eng., **9,** 135 (1932)

The settlement and filtration plant for the water used to wash grit out of flue gases at the Derby Corporation Electricity Works is described and illustrated. The gas is passed through four screens of highly atomized water and the collected slurry (about 5000 gal. an hour, containing about 5 per cent by volume of solid matter) is settled in a tank with a sludge scraper arm (Hardinge thickener). The overflow can be re-used or discharged to the stream. The thickened slurry (about 40 per cent water) is pumped to a Rovac filter trough. The filter consists of a drum, part of which dips into the trough. The drum is slowly rotated, the part dipping into the trough being exhausted by a vacuum pump. Suspended matter is prevented from settling in the slurry by agitators and forms a cake on the canvas surface of the filter which is removed by a stationary knife. The cake contains about 20 per cent moisture and is dry enough for transport. The clear water is discharged into a receiver tank. *Summary of Current Lit.* (British) Water Pollution Research Bd., **8,** Abs. No. 1019 (Aug., 1932).

New Wash Water Clarification Process in Coal Mining

By G. Graf

Glückauf, **68,** 304 (1932)

A wash water clarification plant (Henry process) installed in the Dutch mine Willem-Sophia, which uses a closed system of wash water circulation, treats the water first with lime and then with a mixture of potato flour and

potash. The potato flour is reduced to −6° C. and the potash heated to 75° C. before mixing. After a few hours' settlement a sludge with 25–30 per cent moisture and a clear effluent are obtained. The treatment increases the hardness of the wash water from 10° (French) to 60°; 2000 cm. (about 10 per cent) of water are treated a day, keeping the accumulation of solid matter in the wash water to 15–20 gm. a liter. For this quantity 12 kg. of potato flour, 22 kg. of potash and 451 kg. of lime are used. The total cost, allowing for the recovery of extra sludge by the improved settling is calculated at 2.4 Pf. per cm. of water clarified. In a new plant, however, the diminution in settling time would permit of a large saving in settling space. A high salt content in the water interferes with settling but the presence of clay is probably of advantage.

In discussion, Winkhaus discussed the theoretical effects and practical results of the use of lime, potato flour, frozen and unfrozen, with soda lye and starch in increasing the rate of settlement in coal-washing water. (*Iron and Coal Trades Rev.*, **1932,** 124, 765; *Gas J.*, **1932,** 198, 145.) *Summary of Current Lit.* (British) Water Pollution Research Bd., **8,** Abs. No. 1012 (Aug. 1932).

The Quality of Water Supplies and the Disposal of Sewage

BY BEYREIS

Z. f. Medicinalbeamte, **43,** No. 4 (1930)
Wasser u. Abwasser, **27,** 147 (1930)

The author is of the opinion that at Pforzheim, Mulheim on the Rhine, and other places where the water supply is polluted by sewage, the surface supply should be abandoned and well and ground water used instead. Chlorination has been relied on at water works to ensure a safe supply but it failed during the winter of 1929, owing to the fact that at temperatures below 80° C. chlorine forms chlorine hydrate which separates. Many towns discharge sewage without disinfection, resulting in pollution of water supplies and outbreaks of disease. It is recommended that the water-sewage-water cycle should be avoided, that medical advice should be asked concerning the erection of new works, and that only harmless material should be discharged to water from which water supplies are drawn. *Summary of Current Lit.* (British) Water Pollution Research Bd., **7,** Abs. No. 917 (July, 1932).